STRENGTH GROUPING OF REGROWTH EUCALYPTUS REGNANS

by

SHWE THEIN

Thesis submitted for the degree of Master of Science in the Australian National University.

March 1988

Except where specific reference is made to the work of another person, the research reported in this thesis is original.

Shwe Thein

Shwe Thein

March 1988

ACKNOWLEDGEMENTS

Firstly and especially, I wish to thank deeply my supervisors, Mr. D.M. Stodart (the Department of Forestry of the ANU) for his devotion in this project and his guidance and critical comments in the preparation of the thesis, Mr. K.W. Groves (the Department of Forestry of the ANU) for his guidance during undertaking experiments and his critical comments and correction of English in the preparation of the thesis and Mr. D.J. Grant (the Forestry Commission of NSW) for his guidance in testing and for his critical comments and suggestions in the preparation of the thesis.

This project would have been impractical without the co-operation of the "Young Eucalypt Program". Particularly I thank sincerely Mr. Gary Waugh of the CSIRO and leader of the milling and harvesting project under the Young Eucalypt Programme for providing timbers for mechanical testing, - and his family for their hospitality during the sample collection. I also thank Mr. A. Rozsa, Mr. G. Harris and Mr. K. White of the CSIRO for their assistance in sample collection.

I wish to thank the Forestry Commission of N.S.W. for allowing me to use the controlled testing facility at the timber engineering section and to staff at the section for their assistance in setting up the machines.

I am grateful to Mr. P. Griffiths for his companionship and assistance in the preparation of small clear specimens, to Mr. K. Elliot for his energetic preparation of small clear specimens, to several other members of the staff of the ANU Department of Forestry for their technical assistance, and to my friends U Khin Maung Lwin and U Than Myint for their practical assistance in testing and computation.

I extend my thanks to Mr. R. Cunningham (the Department of Statistics) for his statistical guidance, Mrs. C. Donnelly for her work of fitting distributions, and my friend U Nyan Myint for the provision of a computer programme to calculate random normal deviates and assistance in the application of the programme.

My thanks are due to the Ambassador of The Socialist Republic Of The Union Of Burma and family, and "Uncle George" who "make me at home" like my relatives.

Finally I wish to express deeply my thanks to my parents and U Than Myint who took the responsibility for my personal affairs in Burma and young "Sanda" who always encourages me to move a step forward.

ABSTRACT

The results of a study of strength grouping of the wood of regrowth *Eucalyptus regnans* are reported. Samples were taken of 1927 regrowth from Scottsdale, Tasmania and 1939 regrowth from Powelltown, Murrindindi, Marysville, Mt. Erica, Noojee and Toolangi, Victoria.

The study indicated the strength groups of regrowth were lower than for mature wood.

The Strength Grouping of 60 years old Scottsdale regrowth was not higher than that of 48 years old regrowth from Victoria.

A variation in strength groups was found within the 1939 regrowth. The variation was not related to topographic elevation. For the localities samples, the minimun strength groups were S5 and SD5 for unseasoned and seasoned timber respectively. 'Synthetic' strength groups based on a synthesis of the results from six localities were S4 and SD4.

No strong relationship was found between MOR and either small end diameter or height in the tree at which the small end diameter was measured and it was concluded that strength properties are not strongly related to rate of growth in the even aged stands sampled.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

CHAPTER I. INTRODUCTION

1.1. STRUCTURAL USE AND MECHANICAL PROPERTIES OF TIMBER

Timber has been used extensively for structural and non-structural purposes throughout human history although its properties were not thoroughly understood. For example, it was used in making furniture, sculptures, coffins and death masks as early as 2500 BC, elaborate wooden couches and beds in 700 BC, handles of weapons and tools, construction of huts and rough canoes in the days of Ancient Britain, timber framing of houses, boats and manufacture of musical instruments in mediaeval times. It was widely used as a construction material in the industrial era of the 19th century, in house-framing and also in making furniture, water-wheels, gear wheels, the rails of early pit railways, sleepers, signal poles and boats (Dinwoodie, 1981). In the present century, there has been an extension of its use in some areas but a decline in others due to its replacement by newer materials such as plastic and light weight materials.

The superiorities of timber as a structural material (Beckett, 1986) are as follows:

1. It is light and easy to handle, cut, drill and nail.
2. It has a high resistance to shock loading and to loads of short duration.
3. Thermal expansion and contraction are very small.
4. Large size members do not quickly lose their structural rigidity in a fire.
5. Properly treated, it requires little maintenance.

Its application as a structural material is limited by the following, Beckett (1986):

1. Wood is a natural product and thus not produced to meet a specific requirement.

2. It's strength properties are highly variable, between and within species

and even within a tree.

3. The strength properties of a piece of timber are influenced by moisture content and warping, bowing, cupping or undesirable deflection may be caused by changes in moisture content.

4. Creep of timber is large compared to many other structural materials such as steel and concrete.

5. The sizes and lengths of timber available are limited by log sizes.

6. Small dimension timbers are extremely sensitive to fire.

A piece of timber changes in linear dimension when it is subject to an external force or forces. The external force or forces generate internal stresses in the wood; usually stated on a per unit area basis. The change in dimension is stated per unit of original dimension and is called the strain. Stress and strain are assumed to have a linear relationship within the proportional limit; the proportionality constant between stress and strain is then called the modulus of elasticity. Beyond the proportional limit the relation cannot be assumed to be linear.

Three basic types of stress occur in a piece of timber; compression, tension and shear. Compression stress is associated with shortening of timber; tensile stress with elongation and shear stress with the tendency for one part to slide over another. The level of each stress at which failure of the wood occurs is very variable but it is a necessary requirement for structural use that stresses induced by loads applied to a structure do not cause failure.

Many structural design theories provide for the prediction of stress levels generated in a structure by applied loads. The levels of stress are determined by, inter-alia, the dimensions of the structural members of the structure. Thus dimensions of structural members to keep induced stresses below levels which may cause failure requires definition of safe levels.

The inherent variability of wood presents unique difficulties in defining these safe levels of stress.

1.2. VARIABILITY IN THE MECHANICAL PROPERTIES OF TIMBER

There are over 20,000 woody species, Jane (1970) their variability in strength properties is extremely high. The extent of the variation in three strength properties over 174 selected Australian timbers is given in Table 1.1. Clearly, efficient structural use of timber requires classification in terms of strength properties; otherwise the levels of stress permitted in structures would have to be kept to levels appropriate to the weakest timber or the design process based on the properties of individual species.

Table 1.1. The variation in the mean values of three strength properties of 174 Australian species.

Property[1)]	Moisture condition	Mean value		
		Minimum	Maximum	Range
Modulus of Rupture [MPa]	green	29	145	116
	dry	37	183	146
Modulus of Elasticity [GPa]	green	5.3	19.6	14.3
	dry	6.8	24.6	17.7
Maximum Crushing Strength [MPa]	green	16	85.5	69.5
	dry	24	100.7	76.7

Source - Bolza and Kloot, 1963.
1) The properties are defined in Appendix 1.

However mean values within a species are also highly variable. For example the species mean value for the Modulus of Rupture of unseasoned mature Eucalyptus regnans, F.Muell.is 63.2 MPa but with a coefficient of variation[1] (C.V) of 15.25%(Bolza and Kloot, 1963). The mean value for Modulus of Elasticity is 13.0 GPa with a C.V of 17.50%. The mean value for Maximum Crushing Strength is 29.59 MPa with a C.V of 12.50%. The C.V of the species mean values varies between species. Table 1.2 shows the C.V of the species mean values for Modulus of Rupture of unseasoned timber from three mature 'ash-type' eucalypts.

---

1 C.V indicates the variability of a species mean value. It is defined in Appendix 1.

Table 1.2. Coefficient of variation of the species mean value for Modulus of Rupture of unseasoned timber of three mature 'ash-type' eucalypts.

Species	Species mean [MPa]	C.V %
E. regnans	63.2	15.3
E. delegatensis	68.5	12.5
E. obliqua	71.0	9.5

Source - Bolza and Kloot, 1963.

These variabilities make the classification of timber for efficient structural use difficult and call for systematic procedures to facilitate the specification of timber properties for specific engineering design. Strength grouping is one such procedure and classifies the large number of species into groups. The procedure is discussed in detail in Chapter 2. The grouping is based on test results from mature trees for application to timber design and is utilized for example in Australian Standard 1720 - Timber Engineering Code.

In Australia, there is considerable area of forest known generally as regrowth eucalypts. Stands of regrowth 'ash type' eucalypts are a particularly important resource for the foreseeable future. However, there is evidence which indicates that, for the same species, the 'regrowth' may have different properties to 'old growth' timber (Page, 1965). Breitinger (1987) found the 1939 regrowth E. regnans from Mt. Erica and Powelltown has a strength group for unseasoned timber that is one strength group lower than the unseasoned wood of mature E. regnans. The 1939 regrowth E. regnans from Mt. Erica has a strength group for seasoned timber that is two strength groups lower than that of mature E. regnans.

These results signal problems in the direct application of the strength grouping system to regrowth eucalypts since they indicate significant differences in strength group for regrowth and mature wood of the same species and in the relative changes in strength properties of regrowth and mature timber as they are seasoned. In the study to be reported, the strength grouping of regrowth E. regnans is examined from first principles by mechanical testing of specimens; the results are then compared with those already reported and accepted for mature E. regnans. The studies were undertaken in association with the Young Eucalypt Program.

1.3. THE YOUNG EUCALYPT PROGRAM

The "Young Eucalypt Program" is co-operative research into the growth, harvesting and use of eucalypt regrowth. The objectives of the program are to increase the contribution the regrowth forests make to the Australian community, by evaluating ideas as to how science and technology can be applied to improve the growth, harvesting and utilization of regrowth forests and devising procedures whereby research results can be transferred rapidly to developmental and operational forestry programs. The CSIRO Division of Forestry and Forest Products, the Tasmanian Forestry Commission, the Victorian Department of Conservation, Forests and Lands and the Forest Industries of Tasmania and Victoria, are the cooperating groups. Research areas include 'Thinning and Harvesting', 'Stand damage', 'Growth Response', 'Debarking', 'Sawn Timber Production', 'Pulping' and 'Resources and Markets'.

The studies reported here were carried out at the Department of Forestry, Australian National University in association with other research into 'Sawn Timber Production' by CSIRO.

1.4. THE STUDY AIMS

The reported differences in the properties of wood obtained from mature and regrowth eucalypt stands are limited and the main aim of this study was to determine the magnitude of the difference in the strength properties of timber from regrowth and mature 'ash-type' eucalypt forests and to determine if diameter, height and age of tree and basic density could be used as effective discriminators of the strength properties of regrowth timber.

1.5. PREVIEW OF MATERIALS AND METHODS

Generally, testing of small clear timber specimens was undertaken to enable positive strength grouping in accordance with Australian standard (AS2878, 1986). These procedures are described in Chapter 2.

Since the project was undertaken in association with the "Young Eucalypt Program" and material was available for the preparation of test specimens from stands of 1927 regrowth E. regnans at Scottsdale Tasmania, the first test series was undertaken with this material. A large number of specimens were tested to facilitate statistical studies of the distribution of the results as reported in Chapter 3. This regrowth material has a different strength group to mature E. regnans.

As this study and the "Young Eucalypt Program" developed there was the opportunity to obtain material for the preparation of test specimens from 1939 regrowth stands of E. regnans at Toolangi, Victoria. The results of these studies are also reported in Chapter 3.

The analysis of the test results of the Scottsdale and Toolangi material indicated a need for further sampling of 1939 regrowth E. regnans; test specimens were obtained from five areas in Victoria. The results of these studies are reported in Chapter 4.

As the test results were analysed the desirability of distinguishing strength groups for one species according to whether the wood came from regrowth or mature stands became clear. This would be a significant departure from the accepted practice of one strength group for all the wood obtained from a particular species. These matters are discussed in Chapter 5.

CHAPTER 2. STRENGTH GROUPING AND STRESS GRADING OF TIMBERS [Review]

2.1. INTRODUCTION

In Australia, 788 species of timbers are used for structural purposes (AS 2878, 1986). Pong Sono (1974) lists approximately 200 species of merchantable timbers in Thailand. Wong and Wong (1980) state that 650 species are marketed in Malaysia. Epsiloy (1978) notes that in the Philippines there are over 2000 species of which several hundred are presently merchantable. In Burma (Rodger, 1963), there are at least 200 species that could be considered for structural purposes.

The specification of the strength properties of each species for structural design purposes involves an enormous sampling and testing program. For example, Australian Standard AS 1720 Timber Engineering Code lists eight strength parameters for engineering design and with the variability of each of these properties to be determined by repeated tests within each species it is clear that the testing task is enormous. While much testing has been undertaken, considerable research effort has also been undertaken to group species with strength properties within defined ranges and to adopt the same engineering design criteria for all species within a strength group. There are also advantages from strength grouping in reducing the amount of information to be presented in providing the design information to engineers; instead of listing strength properties for every species the properties are listed for the defined number of strength groups for example in Australia the 788 species are reduced to seven groups for green timber and eight for dry.

The development of strength grouping systems is described later in this chapter. Most systems are based on measuring selected strength properties by testing timber specimens. The derivation of stress grade series, relating basic engineering design stresses to strength group systems, and the incorporation of allowances for defect by reduction in design stresses are also discussed in this chapter.

2.2. STRENGTH GROUPS FOR TIMBER

2.2.1. INTRODUCTION TO THE AUSTRALIAN STRENGTH GROUPING SYSTEM

In Australia a system of strength grouping was first adopted in early 1940. Four strength groups denoted by A, B, C and D in descending order of strength properties (Table 2.1) were defined. Four strength properties namely Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Maximum Crushing Strength (MCS) and Maximum Shear Strength (MSS) were the parameters used to determine the strength group of a species. Species mean values for these strength properties obtained from standard tests on small clear specimens indicated the strength group (Pearson, et al, 1961). The Australian strength grouping system has been widely adapted elsewhere.

Table 2.1. Old Australian Strength group minimum limits for unseasoned timbers in Imperial units[1)]

Group	MOR [psi]		MOE [psi] (in thousands)		MCS [psi]		Shear str. [psi]	
	Green	12%M.C	Green	12%M.C	Green	12%M.C	Green	12%M.C
A	15000	24000	2400	3000	7500	12000	2000	2500
B	12000	20000	2100	2600	6000	10000	1500	1900
C	10000	16000	1700	2200	5000	8000	1200	1600
D	7000	12000	1500	1900	3500	6000	800	1100

Source - Pearson, Kloot & Boyd (1962)
1) Imperial units are shown to indicate the rounding

A feature of Table 2.1 should be noted the relationships between the four parameters are accepted as consistent for all species in the strength group.

In classifying a species to a strength group on the basis of the four properties it may be necessary to exercise some judgement. For example, test results should be obtained for both green and dry material. It could be, given the variability of wood that all but one of the values are within any one range implied by Table 2.1 and that one is below the range. The judgement in this example would be to classify in accordance with all but one of the test values or classify on the basis of the single lower value.

This strength grouping system was established on limited information and was not efficient for the following reasons (Pearson, 1965):

1. Information about the properties of many species had since become available and should be considered in defining the parameters of the groups.

2. The range of each group was "unnecessarily variable".

3. The relations between the average values set for the different properties in each group were not optimized, particularly in the case of MOE.

4. The properties of a number of species, including some of the plantation-grown exotic species, were lower than the average values of strength properties for group D and these may also be advantage and having a higher group than A for the strongest species.

5. The strength grouping system was not in line with the wide range of working stresses for the species listed in AS 083 - Sawn South Eastern Australian Eucalypt Hardwoods.

6. The MOE for all grades of material in the same strength group was the same, i.e MOE was not affected by knots and other defects. Cline and Heim (1912) suggested, after experiments on the effect of knots and other defects on the strength properties of 11 North American softwood species, that MOE was not affected by defects and the observed decrease in MOE was due to increased height in tree. It was later shown that this was not correct (Pearson, op cit).

7. The preparation of a proposed code for a proposed light timber framing called for a review of working stresses applicable to the strength groups.

8. Machine stress grading was under consideration and strength grouping was reviewed in relation to the data provided by machine stress grading.

Pearson (op cit) then proposed a revised strength grouping and stress grading system which, with some amendments, is the basis of the present Australian strength grouping system.

Positive strength grouping is defined as the classification of a timber species into a group on the basis of the mechanical properties of defect-free material of the species. Provisional strength grouping is defined as the classification of a timber species into a group on the basis of its air dry density (AS-2878, 1986). The idea of strength grouping is to provide convenience in marketing and structural use in terms of a few hypothetical numbers (strength groups) each of which possesses certain strength properties rather than in terms of the strength properties of each of the very large number of individual species.

Pearson (1965) first considered Modulus of Rupture, Modulus of Elasticity, Maximum Crushing Strength, Maximum Shear Strength, basic density (for unseasoned timber) and density at 12% moisture content as parameters for strength grouping. Pearson (1966) excluded Modulus of Rigidity and stress at the limit of proportionality in side grain bearing from strength grouping. The Standards Association of Australia (MP45, 1985) excluded Maximum Shear Strength because strength grouping is primarily to give an indication of bending strength and Maximum Shear Strength was not closely related to this. Additionally, density at 12% moisture content is used for both unseasoned and seasoned timber instead of applying basic density to strength group unseasoned timber. Therefore, in the current strength grouping system, the parameters of strength grouping are Modulus of Rupture, Modulus of Elasticity and Maximum Crushing Strength for positive strength grouping and density at 12% moisture content for provisional strength grouping (AS-2878, 1986).

The work done by Cline and Heim (1912) showed that MOE tended to be lower with with increasing defects although the decrease in MOE was suggested as the effect of height in the tree rather than the effect of defects. Chaplin and Nevard

(1935) also reported a similar result based on testing European redwood. In relation to eucalypts, Kloot and Schuster (1958a, 1958b) reported that cross-grain, gum veins and gum pockets affected MOE of jarrah (Eucalyptus marginata Sm.), the effect increasing with an increase in the severity of defects. MOE of structural size timbers of radiata pine was also affected by defects (Pearson op cit) . Pearson tested a total of 58 specimens 8 in. long, taken from 11 low-grade, seasoned, unmatched lengths of 2 x 2 in. radiata pine sawn timbers. Nearly half the specimens had knots, knot clusters, or knot groups of various sizes, representing up to about 75 % of the cross-sectional area; the others were defect-free but cut adjacent to or within a distance of a few inches of specimens with defects. The specimens were tested in compression parallel to the grain. The results indicated a significant relationship between MOE (in compression parallel to the grain) and MCS regardless of the occurrence of defects, that both values were reduced by defects with the reduction in MOE being independent of the variation in the properties of clear wood. Thus, Pearson concluded that MOE in particular is influenced by defects and that procedures for defining strength groups should allow for this.

There is a correlation between strength properties and density of wood. For Australian timbers Pearson (op cit) calculated the correlations between strength properties in small clear specimens using data from Bolza and Kloot (1963)(Table 2.2). He concluded that density at 12% moisture content should be used as a parameter for classifying timber species into strength groups.

Table 2.2. Regressions relating various mechanical properties of Australian timbers

Property[1]	Regression	Corr. Coeff.	No.of species
Bending	$R_g = 252\ BD + 510$	0.89	95
	$R_g = 182\ DD + 1350$	0.86	74
	$E_g = 129\ R_g + 310{,}000$	0.84	76
	$E_d = 161\ R_g + 360{,}000$	0.79	77
	$E_d = 115\ R_d + 180{,}000$	0.93	73
	$R_d = 1.44\ R_g + 1160$	0.88	81
Compression || to G	$C_g = 0.532\ R_g - 220$	0.97	94
	$C_d = 0.680\ R_g + 1750$	0.92	81
Compression _|_ to G	$L_g = 0.147\ R_g - 500$	0.78	74
	$L_d = 0.198\ R_g - 580$	0.84	74
Shear	$S_g = 0.134\ R_g - 40$	0.92	93
	$S_d = 0.140\ R_g + 620$	0.78	77
Modulus of rigidity	$G_g = 7.44\ R_g + 30{,}000$	0.85	65
in torsion	$G_d = 10.3\ R_g + 40{,}000$	0.79	64

Where

BD = basic density (lb/cu.ft.)
DD = density at 12% M.C (lb/ cu.ft.)
C = Maximum crushing strength (lb/sq.in.)
E = Modulus of elasticity (lb/sq.in.)
G = Modulus of rigidity in torsion (lb/sq.in.)
L = stress at limit of proportionality in radial direction on 6*2*2 in. specimen (lb/sq.in.)
R = Modulus of rupture (lb/sq.in.)
S = Maximum shear strength (lb/sq.in.) -- lower of two values for shear in radial and tangential planes
Subscripts 'g' and 'd' refer to green and air-dry (12% M.C) material respectively
1) Species means values from standard tests on small clear specimen.

Source - Pearson (1965)

The analysis showed the correlations between strength properties and unseasoned MOR, and between the latter and basic density or density at 12% M.C as highly significant. Pearson concluded there would be consistent relations between strength properties within a defined strength group. Thus, strength grouping could be developed to provide basic design stresses for dimensioning structural members in accordance with structural design theories. This lead to the development of stress grade systems as discussed later in this chapter.

Pearson also examined relationships between strength properties in structural sizes of timber particularly for MOR and MOE. Pearson plotted MOE against MOR using published data from Cline and Heim (1912), Chaplin and Nevard (1935), Lee et al (1961), Booth and Silvester (1957), Kloot and Schuster (1958a, 1958b) and unpublished data from the New Zealand Forest Service and CSIRO Division of Forest Products. The results suggested that in structural sizes "there is a definite trend of MOE with MOR, although the slopes of any regression lines which might be drawn for individual species would undoubtedly differ considerably". The following equations were established to determine a general relationship between MOE and MOR of structural sizes of beams applicable to aggregates of species and probably also to many individual species:

$$E_g = 176\ R_g + 320\ 000$$

$$E_d = 176\ R_d + 320\ 000$$

where

E = MOE (10^6 lb/sq.in.)

R = MOR (10^3 lb/sq.in.)

subscripts 'g' and 'd' indicate 'green' and 12 % moisture content respectively

Thus Pearson concluded that strength grouping based on testing of small clear timber specimens would also be applicable to structural sizes.

Pearson then considered the range in strength properties to be encompassed by a strength grouping system.

A high proportion, perhaps all, of the wood species in the world could be used for some structural purposes. However the mean values for certain strength properties are available for only about 2000 (Keating, 1981). In Australia, Bolza and Kloot (1963) reported mean values for 174 species but there are over 400 indigenous species that could be used for structural purposes. The species mean values are wide ranging. It was very desirable that a strength grouping system encompass all species while efficient use required the strength properties of a species not to greatly exceed the mean value for the strength group in which it was placed. Safety demanded the species mean value was not unacceptably less than the mean value of the strength group in which it was placed. Thus, while it was important to define as accurately as possible the upper limits of the strength properties it was critical to ensure the lower limit was defined to ensure that all structural timbers were above this limit.

Strength grouping divides the range of mean values into a suitable number of intervals (Figure 2.1). A species can then be assigned to the interval within which its mean value is greater than the minimum limit for that interval. Pearson (op cit) reported an extensive strength grouping system should be developed within which all species could be classified, which could be used internationally but would not necessarily provide for the most efficient use of species.

In this proposal species mean values for MOR, MOE, MCS and density at 12% M.C were suggested as suitable for the determination of strength groups.

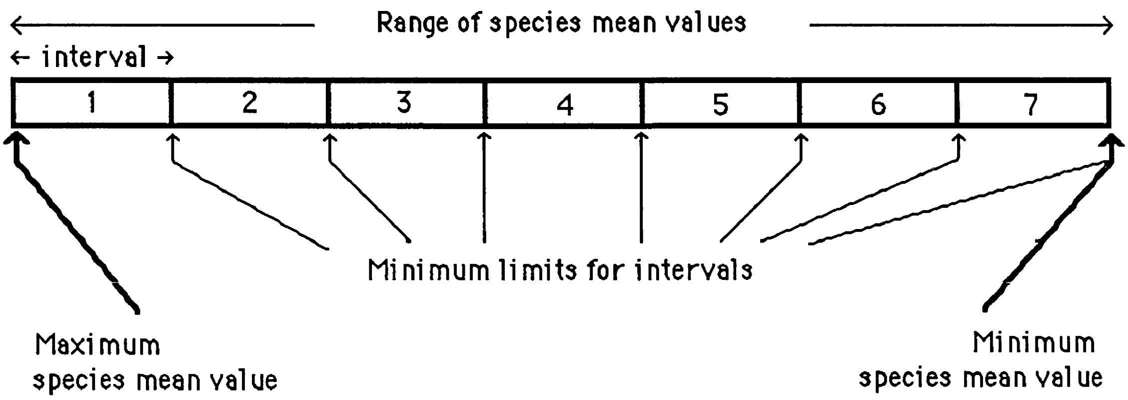


Figure 2.1. Schematic structure of strength groups

In determining the number of strength groups and the differences between minimum limits of successive strength groups the following should be taken into consideration:

1. The fiducial range of the species mean values for the wood

properties forming the basis of classification into a strength group. The fiducial range can be considered as the interval between the 1% lower and higher probability points on the normal curve and can be estimated by standard statistical techniques. It is important in establishing strength groups because if the difference between two strength group limits does not exceed the fiducial range of species mean values, a large number of species could fall within two groups.

2. The progression of strength groups should be systematic in order to apply internationally.

However, the question remains as to how to determine the number of intervals. On the one hand there could be a relatively small number of intervals based on the measurement of the properties of clear timber accepting that, in timber design practice, allowable stresses in timber structures would have to be reduced in a conservative way if defect was present. On the other hand there could be a relatively large number of intervals within which consistent relations between specific strength properties could be applied irrespective of the amount of defect and strength groups could be intervals encompassing several of a relatively large number of small intervals.

Australian practice is discussed in the following sections but it is noted that a relatively large number of intervals (called stress grades) was adopted for all the standard methods in the USA, UK and Australia, Comben (1971) and the intervals of strength groups determined by combining stress grades.

2.2.1.1. Derivation of strength group limits

Pearson (1965) derived strength group limits on the basis of a stress grade series. The basic working stresses in bending for unseasoned timber of structural grade no.1 were chosen as 4000, 3200, 2500, 2000, 1600, 1250 and 1000 psi as a basis for calculating the strength group limits. Initially these values were multiplied by 100/75 (see Appendix 2) that is the basic working stresses for structural grade no.1 were assumed to be 75% of the basic working stresses for clear timber. The group limits were calculated from equation (1).

$$R = (f * F) + (N * S) \tag{1}$$

where
F = basic working stress [MPa] or [psi]
R = Mean value [MPa] or [psi]
S = standard deviation of 'R'[1]
N = statistical constant[2]
f = The allowance for duration of load, accidental overload and other incalculables, and for variation in size of materials (See Appendix 2)

The group limits for MOE, MCS and air dry density were then obtained by the regression equations given in Table 2.2. The resulting strength group limits for the various strength properties are given in Table 2.3.

---

1 Standard deviation for the mean value of Modulus of Rupture was estimated on the basis of data in Bolza and Kloot (1963).

2 This constant indicates the probability below which not more than a particular percentage of the test results will be expected to fall (Comben, 1971), for example the constant for 1% probability, below which not more than one of a hundred test results will fall, is 2.33. It can be obtained from the normal distribution table. In the calculation of strength group limits, the constant for 1% probability was used.

Table 2.3. Minimum group limits for unseasoned timber

Property	Strength group						
	S1	S2	S3	S4	S5	S6	S7
Basic density	60	50	42	35	30	25	21
MOR	16000	13000	11000	9500	8000	6700	5600
MOE	2.40	2.10	1.85	1.60	1.35	1.15	1.00
MCS	8000	6700	5600	4700	4000	3300	2800
MSS	2050	1750	1450	1200	1000	870	730

Note - Basic density is in lb/cu ft; modulus of elasticity in 10^6 lb/sq in; and all other properties are in lb/sq in.
Source - Table 3, Pearson (1965)

Pearson (1966), then, replaced the strength group limits given in Table 2.3 by those in Table 2.4 because he considered giving an allowance of 7% for size effect was unnecessary and also because there was some improvement in consistency of grouping species according to their various properties by basing the group properties for density, modulus of elasticity, compression and shear of seasoned timber on correlations between those of seasoned timber, instead of on the modulus of unseasoned timber.

Table 2.4. Minimum group limits for unseasoned timber after adjustment.

Property	Strength group						
	S1	S2	S3	S4	S5	S6	S7
Basic density	56.0	47.5	40.0	33.5	28.0	23.5	20.0
MOR	15000	12500	10600	9000	7500	6300	5300
MOE	2.36	2.06	1.80	1.55	1.32	1.15	1.0
MCS	7500	6300	5300	4500	3750	3150	2650
MSS	1900	1600	1320	1120	950	800	670

Note - Basic density is in lb/cu ft; modulus of elasticity in 10^6 lb/sq in; and all other properties are in lb/sq in.
Source - Pearson (1966)

Keating (1973) proposed to change the stress grade values in Imperial units to equivalent values in metric units. By metrication the strength group limits shown in Table 2.5 were obtained from Table 2.5 (Kloot, 1973).

Table 2.5. Minimum group limits for unseasoned timber (metric version)

Property	Strength group						
	S1	S2	S3	S4	S5	S6	S7
Basic density (kg/m3)	900	760	640	540	450	375	320
MOR (MPa)	103	86	73	62	52	43	36
MOE (MPa)	16300	14200	12400	10700	9100	7900	6900
MCS (MPa)	52	43	36	31	26	22	18

Source - Kloot, 1973

The strength group limits for seasoned timbers were also obtained (using the regression equations in Table 2.2.) and with metrication are shown eight groups in Table 2.6. In treating the seasoned timbers as a separate population was found appropriate.

Table 2.6 . Minimum group limits for seasoned timber

Property	Strength group							
	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8
Density at 12%M.C (kg/m3)	980	865	770	680	590	520	465	390
MOR (MPa)	150	130	110	94	78	65	55	45
MOE (MPa)	21500	18500	16000	14000	12500	10500	9100	7900
MCS (MPa)	80	70	61	54	47	41	36	30

Source - Kloot, 1973

2.3. METHOD OF STRENGTH GROUPING

Two methods of strength grouping are used depending on the information available on the strength properties of a species (AS-2878, 1986): positive strength grouping and provisional strength grouping.

Positive strength grouping is based on the species mean values for three strength properties i.e MOR, MOE, and MCS. These values are obtained by the standard tests proposed by Mack (1979) on small clear specimens sampled from no fewer than five properly selected trees of each species. A species may be allocated to a provisional strength group when the information required for positive strength grouping is not available provided either the values are available from no fewer than three trees or the species mean value for density at 12% moisture content is obtained from standard measurements on specimens sampled from no fewer than five selected trees of the species.

2.3.1. PROCEDURE FOR POSITIVE STRENGTH GROUPING

Preliminarily a species is grouped using each individual property by comparing the species mean value of the property with the minimum value listed for each strength group in Tables 2.5 and 2.6.

Three strength groups for a species could thus be obtained: one from MOR, one from MOE and one from MCS.

The next step in grouping is to consider the overall species strength group. When the preliminary classification for each property is the same, there is of course no difficulty in determining the overall strength group. However, where the preliminary classifications differ a compromise is effected according to Table 2.7.

Table 2.7. Combinations of preliminary classifications permitting the overall strength group assessment to be one step above the lowest in the combination

Preliminary classification[1]			Assessed overall strength group
MOR	MOE	MCS	
X	X	X + 1	X
X	X - 2	X - 1	X - 1
X	X + 2	X + 1	X + 1

Source - AS 2878 (1986)

1 Strength group X - 1 is stronger than strength group X; e.g. if strength group S4 is denoted by X then strength group S3 is denoted by X - 1.

If the above combinations cannot be applied, the lowest preliminary strength group is decided to be the overall strength group.

2.3.2. PROCEDURE FOR PROVISIONAL STRENGTH GROUPING

When data for strength properties are available from only three trees, the procedure for positive strength grouping is used. However, the overall species strength group is reduced by one step, for example S4 would become S5.

Where data are available only for air-dry density, strength grouping is done by matching the species mean value for air dry density with the minimum value of the strength group shown in Table 2.8 provided measurements are available from at least five trees. Because strength grouping on the basis of density is not precise the results obtained are very conservative (Keating, Personal communication).

Table 2.8. Minimum density values, at 12 percent moisture content, from five or more trees.

(a) Unseasoned material

Strength group	S1	S2	S3	S4	S5	S6	S7
Based on mean density at 12 percent M.C [kg/m3]	1180	1030	900	800	700	600	500

(b) Seasoned material

Strength group	SD1	SD2	SD3	SD4	SD5	SD6	SD7	SD8
Based on mean density at 12 percent M.C [kg/m3]	1200	1080	960	840	730	620	520	420

Source - AS 2878 (1986)

In grouping seasoned timbers either by positive or provisional strength grouping the strength data are adjusted to a moisture content of 12%. (The method of adjustment is given in Appendix 3.)

2.4. STRESS GRADE SERIES

When using timber in structures it must have the properties assumed in the structural design. The strength properties of wood in structural sizes are more variable than those of small clear timber because, in addition to the natural variability of clear wood, there is variability due to the various kinds of defects such as knots and sloping grain. Timber grading systems have been developed which provide for percentage reductions in strength properties according to the amount of defect. For example in AS2082-1979 for visually stress graded hardwood, 'Structural grade no.1' allows for a reduction of 25% relative to defect free timber, 'Structural grade no.2' for 40%, 'Structural grade no.3' for 52% and 'Structural grade no.4' for 62%.

With a rapid increase in the number of species used structurally the application of grading rules species by species would become impracticable. The development of strength grouping has reduced the amount of testing to determine strength properties for engineering design and the reduction in strength due to a fixed amount of defect is assumed to be consistent over the full range of strength properties encompassed by a strength group.

In this study "strength group" was adopted as the main parameter for the comparison of the overall strength properties of regrowth ash timber as it can be obtained without assessing defect. Consideration of stress grades would then be outside the scope of the study. However, test values for Modulus of Rupture can be used to calculate basic working stresses in bending and, in turn, classification of test results in terms of stress grades. Thus the development of the stress grade system is reviewed.

There was a need to establish ranges in strength properties within which consistent reductions in strength could be assumed for a specified amount of defect that is the defined limits would be such that a certain amount of defect, as determined in accordance with grading rules, could be related to a reduction in strength whether the timber had high strength or low strength. The advantage of such grouping and grading systems is of course the simplified application of standard grading rules.

Thus it is now common practice to specify certain timber strength properties in terms of a stress grade. In Australian practice, basic working stresses in bending, tension parallel to the grain, shear in beams, compression perpendicular to the grain and Modulus of Elasticity and Rigidity are related to a stress grade.

With any system of grading or grouping it is necessary to decide on the number of grades or groups, the magnitude of the difference between them and the actual values to be used (Comben, 1971). In fact a geometrical series has been used internationally for stress grades, initially by Johnson (1950) and May (1952). Cooper (1953) then proposed it as a universal series. The major advantage of the geometric series is that the same ratio is sustained between successive members of the series and extension of the series in any direction does not affect the consistency of the ratio.

The present Australian practice is based on a preferred number series proposed by Cooper (op cit). In the establishment of the preferred number series, a stress number of 1000 lb/sq.in. in the Imperial system or 100 kg/sq.cm. in the metric system was arbitrarily chosen and the common ratio of the progression developed from the following three requirements:

1. Simplicity of the series in both the Imperial and the Metric systems with the two systems directly related. The conversion factor between imperial and metric stress units i.e. 14.22 lb/sq.in. = 1 kg/sq.cm, is nearly the same as $\sqrt{2}$ multiplied by 10. Thus a geometric ratio based on $\sqrt{2}$ would provide satisfactory correspondence between the imperial and metric series.

2. The series within both systems should repeat themselves. This could be achieved and the repetition would be sufficiently frequent, if each higher stress is double the value of a particular stress below it.

3. The numbers in the series should be decimalized in both systems.

Based on an initially selected basic stress and the three requirements listed above, a preferred series was proposed for both systems as shown in Table 2.9 which, in fact, eventually satisfied all the requirements listed above.

Table 2.9. Preferred stress series after Cooper (1953)

Imperial System (lb./sq.in.)		Metric System (kg/sq.cm)
100	$10/\sqrt{2}$	7.1
112		8
125		9
140		10
160		11.2
180		12.5
200	$20/\sqrt{2}$	14
224		16
250		18
280		20
315		22.4
355		25
400	$40/\sqrt{2}$	28
450		31.5
500		35.5
560		40
630		45
710		50
800	$80/\sqrt{2}$	56
900		63
1000		71
1120		80
1250		90
1400		100

The series of preferred numbers in Table 2.9 is known as the 20 series because the number of members in a non-repeated part of the series, i.e 112 to 1000 in the Imperial System and 11.2 to 100 in the Metric System is 20 while

Comben (1971) called it the R20 series. The series repeats after every 20th member and the repetition is decimalized. For example, '112' in the Imperial System is repeated as '1120' which is equal to 10 x 112, and the relationship between the two systems is as shown in table 2.9. The series are achieved by having a common ratio within each series of approximately 1.125.

Table 2.10. Basic Working Stresses and Preferred Stress Grades after Cooper (1953)

Basic Working stress	Stress Grade 90%	80%	70%	63%	56%	50%
4000	3550	3150	2800	2500	2240	2000
3550	3150	2800	2500	2240	2000	1800
3150	2800	2500	2240	2000	1800	1600
2800	2500	2240	2000	1800	1600	1400
2500	2240	2000	1800	1600	1400	1250
2240	2000	1800	1600	1400	1250	1120
2000	1800	1600	1400	1250	1120	1000
1800	1600	1400	1250	1120	1000	900
1600	1400	1250	1120	1000	900	800
1400	1250	1120	1000	900	800	710
1250	1120	1000	900	800	710	630
1120	1000	900	800	710	630	560
1000	900	800	710	630	560	500
900	800	710	630	560	500	450
800	710	630	560	500	450	400
710	630	560	500	450	400	355
630	560	500	450	400	355	315
560	500	450	400	355	315	280
500	450	400	355	315	280	250
450	400	355	315	280	250	224
400	355	315	280	250	224	200
355	315	280	250	224	200	180
315	280	250	224	200	180	160
280	250	224	200	180	160	140
250	224	200	180	160	140	125
224	200	180	160	140	125	112
200	180	160	140	125	112	100
180	160	140	125	112	100	90
160	140	125	112	100	90	80
140	125	112	100	90	80	71
125	112	100	90	80	71	63
112	100	90	80	71	63	56
100	90	80	71	63	56	50
90	80	71	63	56	50	45
80	71	63	56	50	45	40
71	63	56	50	45	40	35.5
63	56	50	45	40	35.5	31.5
56	50	45	40	35.5	31.5	28
50	45	40	35.5	31.5	28	25
45	40	35.5	31.5	28	25	22.4
40	35.5	31.5	28	25	22.4	20

The set of preferred stress numbers and a set of proposed basic working stresses are compared in Table 2.10. The basic stress for any species could be rounded off to one of the preferred numbers and preferred stress grades can be established nominally as 90, 80, 70, 63, 56, 50, per cent of the basic working stress for a clear grade. The basic working stress and its related stress grades can be extended in either direction as necessary.

In current Australian practice, a common ratio of 1.25 was chosen for the successive stress grades. The reasons for this are as follows:

1. This ratio was equivalent to the ratio in the old Australian grading system between the successive structural grades select, standard and building.

2. A larger ratio leads to a smaller number of stress grades and, therefore, simplicity but it is less efficient because a lot of material is reduced to the bottom of a broad range. However, the ratio must also allow for the difference between two stress grades to exceed the fiducial range of the mean values of the species classified in the range. Pearson concluded that while more closely spaced working stresses (that is a smaller ratio) would lead to an increase in accuracy it would be more apparent than real and would not warrant the resulting complexity.

The following set of basic working stresses from the series recommended by FAO (1958) was then chosen for developing the Australian system; 10000, 8000, 6300, 5000, 4000, 3200, 2500, 2000, 1600, 1250, 1000 (psi). Lower values could be obtained by dividing the lowest value by 1.25 e.g 1000/1.25 = 800 psi or by omitting the final zero of each value e.g from 8000, 6300, etc to 800, 630, etc. These values were described as 10000f, 8000f, 6300f, etc each of which refers to a stress grade. Stress grades were thus related to basic working stresses and, as those words imply, to the stresses that should be adopted as the design stresses in a structure.

It was assumed the set of basic working stresses given above would apply to the working stresses for select grade (75%), unseasoned material of each strength group under dead load, and that values above 4000 could be omitted as being too high for these conditions (Pearson, 1965); The series of stress grades for select grade unseasoned timber i.e. 4000f, 3200f, 2500f, etc was subsequently metricated as shown in Table 2.11.

Table 2.11. Metrication of stress grade series for unseasoned timbers (Keating, 1973)

Imperial stress grade	Basic working stress in bending [lb/in^2]	[MPa]	Metric stress grade
4000f	4000	27.5	F27
3200f	3200	22.0	F22
2500f	2500	17.0	F17
2000f	2000	14.0	F14
1600f	1600	11.0	F11
1250f	1250	8.6	F8
1000f	1000	6.9	F7
800f	800	5.5	F5
630f	630	4.3	F4
500f	500	3.4	F3
400f	400	2.8	F2

The basic working stresses for other strength properties can be derived using the regression equations in Table 2.2. These are shown in Table 2.12.

Table 2.12. Basic working stresses and elastic constants for sawn timber in MPa

Stress	Type of stress				MOE	Modulus of
grade	Bending	Tension ‖ G	Shear in beams	MCS		rigidity
F34	34.5	20.7	2.45	26.0	21500	1430
F27	27.5	16.5	2.05	20.5	18500	1230
F22	22.0	13.2	1.70	16.5	16000	1070
F17	17.0	10.2	1.45	13.0	14000	930
F14	14.0	8.4	1.25	10.5	12200	830
F11	11.0	6.6	1.05	8.3	10500	700
F8	8.6	5.2	0.86	6.6	9100	610
F7	6.9	4.1	0.72	5.2	7900	530
F5	5.5	3.3	0.62	4.1	6900	460
F4	4.3	2.6	0.52	3.3	6100	410
F3	3.4	2.0	0.43	2.6	5200	350
F2	2.8	1.7	0.36	2.1	4500	300

Thus the stress grade system implies a combination of basic working stresses for various strength properties. For example, F14 generally has a bending strength of 14 MPa, a tensile strength of 9.8 MPa, a shear strength (in a beam) of 1.25 MPa, a maximum crushing strength of 10.5 MPa and a modulus of elasticity of 12200 MPa.

2.5. ESTABLISHMENT OF STRUCTURAL GRADES

Structural grades take account of the reduction in strength by defect and are defined as percentages of the basic working stress for small clear timber. In Australian practice, the highest structural grade is chosen as 75% of the basic working stress for small clear timber, the ratio between two successive structural grades being 1.25 to 1, the same as between two successive stress grades. The number of structural grades is 5 for softwood (AS 2858, 1986) and 4 for hardwood (AS 2082, 1979). The percentages of the basic working stress of small clear timber are 75%, 60%, 48%, 38% and 30% respectively for structural grades no.1 to 5 in softwoods and 75%, 60%, 48% and 38% respectively for structural grades no.1 to 4 in hardwoods.

2.6. RELATIONSHIP BETWEEN STRENGTH GROUPS, STRESS GRADES AND STRUCTURAL GRADES

A strength grouping system is established on the basis of the strength properties of small clear specimens. Stress grade series and structural grades are established for structural size timbers which usually contain defects. The relationship between strength groups, stress grades and structural grades for unseasoned hardwood are shown in Table 2.13 (AS 2082, 1979). In unseasoned timber, there is, in fact, a direct relationship between strength groups, stress grades and structural grades because strength groups and structural grades are developed on the basis of a stress grade series. However, a direct relationship between strength groups, stress grades and structural grades cannot be established for seasoned timber because the established strength group limits are calculated from the regressions in Table 2.2. The relationships can only be adapted and these are presented in Table 2.14 (AS 2082, 1979).

Table 2.13. Relationship between strength groups and stress grades for unseasoned timber.

Strength group	Stress grade			
	Structural no.1	Structural no.2	Structural no.3	Structural no.4
S1	F27	F22	F17	F14
S2	F22	F17	F14	F11
S3	F17	F14	F11	F8
S4	F14	F11	F8	F7
S5	F11	F8	F7	F5
S6	F8	F7	F5	F4
S7	F7	F5	-	-

Table 2.14. Relationship between strength groups and stress grades for seasoned timber.

Strength group	Stress grade			
	Structural no.1	Structural no.2	Structural no.3	Structural no.4
SD1	F43	F34	F27	F22
SD2	F34	F27	F22	F17
SD3	F27	F22	F17	F14
SD4	F22	F17	F14	F11
SD5	F17	F14	F11	F8
SD6	F14	F11	F8	F7
SD7	F11	F8	F7	F5
SD8	F8	F7	F5	F4

CHAPTER 3. PRELIMINARY STUDIES TO STRENGTH GROUP

3.1. INTRODUCTION

In Victoria there are two commercially important species of 'ash' eucalypts. These are Eucalyptus regnans, F. Muell. (mountain ash), and E. delegatensis (alpine ash). In Tasmania the two 'ash' species are marketed together with E. obliqua (messmate). The three species each have their own individual strength group but together form a group known commercially as Tasmanian oak. The grouping of the commercial mixture is based on the species with the lowest rating and the mixture is subject to the same grading rules.

In this study only E. regnans was investigated.

3.2. EUCALYPTUS REGNANS

Geographic distribution

E. regnans occurs in Victoria and Tasmania in discontinuous areas between latitudes 37° and 43°S. In Victoria it is mainly restricted to mountains south of the Great Dividing Range in the eastern part of the state but there is an occurrence in the Otway Ranges, south west of Melbourne. In Tasmania, it occurs principally in the northeast, the southeast and in the valleys of the Huon and Derwent Rivers (Hall et al. 1970). The approximate natural distribution of E. regnans has been mapped by Eldridge (1972). The altitudinal range is 120 - 1100 m in Victoria and 30 - 610 m in Tasmania.

Climatic zone

E. regnans is found within a narrow range of climatic conditions that is a moist environment with a mean annual precipitation from 1200 to 2000 mm, absence of long periods of water stress, shelter from both hot and cold strong winds and free air drainage to reduce the effects of frost. The mean monthly temperatures vary from a maximum of 17°C in January to 5°C in

July that is mild in summer and cool in winter. Frosts are infrequent at low altitudes but 80 or more per annum may be recorded at higher elevations (Hall et al. 1970). Snow is common in winter at the higher altitudes but does not lie on the ground more than a few days.

Soils and sites

In natural stands E. regnans attains its best development in sheltered mountain valleys on deep, fertile loamy soils that are moist but well drained. In Tasmania, it occurs on normal podsols with parent materials including limestone and dolerite (Hall et al. 1963). In Victoria it occurs mainly on upland and mountain podsols on krasnozem soils derived from feldspathic sandstones, mudstones and granites and less frequently on dacite and porphyry.

It typically grows in rather open, pure stands. Where the soil is less fertile and rainfall lower the pure stands may be confined to valleys and along watercourses (Hall et al. 1970). Although E. regnans may occur in swampy flats along creeks, it grows poorly on permanently saturated sub-soils (Ashton 1976).

Old growth E. regnans forests have been largely replaced by regrowth. In Victoria a major component of the regrowth forests derive from the stands regenerated after the 1939 fire. Since 1930 regrowth forests have also been established by silvicultural practice rather than natural causes. The total area of eucalypt forests established in Victoria and Tasmania since 1950 is shown in Table 3.1.

Table 3.1. Eucalypts established in Victoria and Tasmania since 1950

Category	Natural regeneration	Planted	Total
Victoria			
State Forests and State owned concessions [ha]	94700	7800	102500
Private [ha]		6200	6200
TOTAL [ha]	94700	14000	108700
Tasmania			
State forests and State owned concessions [ha]	77700	3700	81400
Private [ha]	50000	11300	61300
TOTAL [ha]	127700	15000	142700

Source - Young Eucalypt Program (1987)

These regrowth eucalypt forests have been an important source of wood since 1980 but production and utilization problems have emerged. For example, the wood quality of the regrowth stands is generally regarded as inferior to that obtained from mature stands. This study has examined regrowth material in terms of the strength grouping system and of the strength group to which the mature mountain ash has been assigned in particular.

3.3. ASSESSMENT OF POTENTIAL TESTING PROGRAMME

The feasibility of a research project on strength grouping depends on the availability of timber required for testing. It is essential to ensure that the material tested represents the whole of the material. After Mack (1979) the steps followed in obtaining material should be

1. Select stands to be sampled

2. Sample trees in the stands

3. Select specimens from the trees.

The field work to be done in forests is expensive and time consuming requiring labour for operations such as measuring the diameter and height of trees and felling and logging. On the other hand, the precision of results of the research is important and is dependent on the intensity of sampling and thoroughness and care during all procedures. Furthermore, the locations of stands of a species in natural forests are irregular and proper sampling requires knowledge of the extent of the species otherwise trees sampled may not be representative.

Timber from 1927 regrowth E. regnans at Scottsdale, Tasmania was available through the "Young Eucalypt Program" and, in connection with that programme, further sampling was proposed. The availability of this timber and the lack of test data regarding its strength properties and potential strength group were major factors in the initial choice and the development of the research undertaken.

Potentially timber additional to that from Scottsdale and available for the preparation of test specimens to enable strength grouping was as follows.

1.1939 regrowth E. regnans from Toolangi, Victoria. The trees had been felled and logs were to be milled at the training sawmill at Creswick, Victoria.

2. Logs obtained from adjacent thinned and unthinned stands of 1939 regrowth E. regnans from Toolangi, Victoria.

3. A pack of timber containing a variety of regrowth and plantation grown ash type eucalypts from Tasmania.

It was concluded that this material would provide for the study of the variation in strength properties of regrowth ash in relation to species, site, age, rate of growth and silvicultural treatment. However, changes were made in the 'Young Eucalypt Program' and the logs from the thinned and unthinned stands and the pack of timber did not become available. Sampling at mill sites was therefore undertaken.

Sampling for material to prepare test specimens from the Scottsdale was opportunistic for the Scottsdale site. A pack of sawn scantling was at the Division of Building Research, CSIRO, Melbourne. It contained timber from a number of trees, each piece of timber was marked and could be related to a particular tree and log from that tree. Diameters of the trees were available. A formal sampling was formulated for the Toolangi material.

It was decided to use those materials i.e. from Scottsdale and Toolangi, for initial experiments to examine for relations between rate of growth of the tree and strength properties. The experiments were seen as preliminary study. It was later related to studies of 1939 regrowth E. regnans from Victoria.

3.4. STRENGTH GROUPING REGROWTH E. regnans FROM SCOTTSDALE (TASMANIA) AND TOOLANGI (VICTORIA)

3.4.1. MATERIALS AND METHODS

3.4.1.1. Preliminary preparation of Scottsdale wood

Sixteen trees (E. regnans, F. Muell.) were selected at Scottsdale, Tasmania. The trees were approximately 60 years old, i.e. derived from 1927 regrowth. Logs were milled in Tasmania and 78 boards were selected for detailed investigation. Each board was marked with respect to the tree and log from which it was milled and shipped to Melbourne. After selecting 38 boards for seasoning research at the CSIRO Division of Building Research, forty boards 1 to 2.5 meters in length, 50 mm thickness and of various widths were wrapped in plastic to keep them green and stored for future use in a shed. Defect free specimens for the strength grouping study were subsequently obtained from this green material. There were no signs of microbiological decay.

End splitting of the boards occurred during storage and 100 to 200 mm were removed from one end of each board to ensure that green material without splits was sampled. Sections with unacceptable gum veins and gum pockets were also removed from the boards to ensure defect-free specimens. Samples 600 mm long were then cut from the remaining board lengths. The samples were wrapped in plastic to prevent drying and taken to the Department of Forestry, ANU to prepare small clear specimens for testing. The samples were kept under water for several weeks until the test specimens were prepared. There was no sign of microbiological decay when the specimens were prepared

3.4.1.2. Sampling and preliminary preparation of Toolangi wood

1939 regrowth E. regnans trees were selected at Toolangi, Victoria, in connection with the "Young Eucalypt Program", measured for over-bark diameter at breast height (DBHOB) and divided into three diameter classes. Three trees were selected randomly from each diameter class. The trees selected are listed in Table 3.2.

Table 3.2. 1939 regrowth E. regnans trees selected at Toolangi, Victoria.

Diameter class [mm]	Tree number	DBHOB [mm]
400 - 450	1	450
	2	410
	3	440
500 - 550	4	510
	5	520
	6	520
600 - 650	7	620
	8	620
	9	630

The trees selected were felled and cut into long-length logs. Generally each tree was cut into three logs; those with shorter stems into two. Generally these long-length logs were cut into two sawlogs 5.5 m long at the sawmill but some small diameter top logs were cut into three sawlogs 3.6 m long. The list of sawlogs is shown in Appendix 4.

Although taper occurs in all logs and cross sections are usually not circular the ends of logs are usually described by small end and large end diameters. In milling practice the small end of a sawlog is more important than the large end since it has more influence on the sawing pattern. In designing a sampling plan to obtain test specimens for measuring strength properties each log was assumed to be a solid cylinder of a diameter equal to that of the small end of the log (Figure 3.1).

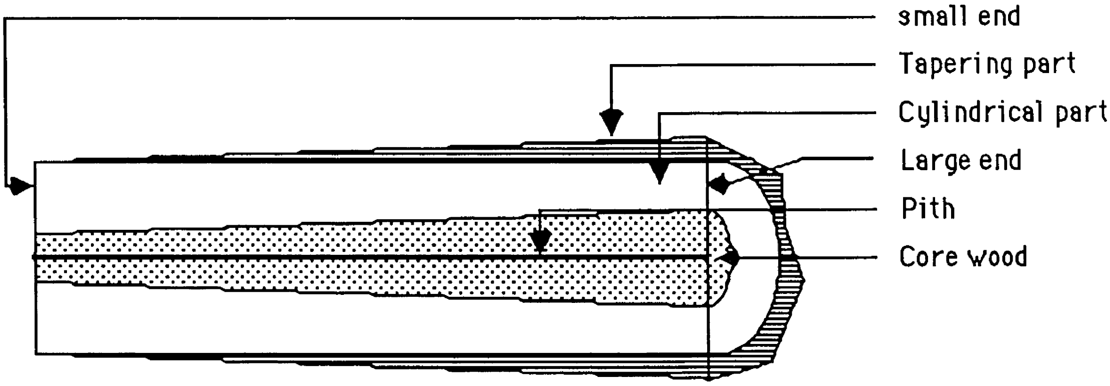


Figure 3.1. Schematic diagram of a log.

The sawlog illustrated has pith which is surrounded by core wood of low quality for structural purposes. This part of a log should be excluded from structural timber and from the wood sampled for strength tests. However, the extent and occurrence of core wood in regrowth eucalypts is not known. It may vary between trees and perhaps within a tree, depending on tree growth. Therefore, in designing the sampling plan, core wood was not excluded.

Specimen sampling was done in two steps; sampling over the small end and sampling through the length of a log. The former was done before milling; the latter after milling.

The small end cross-section of a log was divided into 30 equal sectors of an assumed circle. Six of the thirty sectors were then randomly selected. Since the number of trees and sawlogs were known in advance this was done with the computer by generating sets of six random numbers from the integer set one to thirty.

A specimen portion then had to be selected within each sector. In theory this should be done by dividing each sector into a given number of equal areas. Since the radius of each sector was not known in advance of milling, the area of each sector could not be calculated before sampling at the sawmill. On the other hand, it would be difficult and probably impracticable to divide a sector into equal areas when the sawlog was placed on the mill deck. Therefore, instead of selecting an area within a sector, a point where the specimen was to be obtained was sampled along the radius across the middle of the sector in the following way:

A sector is divided into 10 divisions of equal area, one of which is to be selected randomly (Figure 3.2).

Here $R_1, R_2, R_3, \ldots\ldots, R_{10}$ = Radial distance to the outer boundary of the equal areas

R_x = Radius of the sector

Q = Angle (radian) subtended by the sector at the centre of the circular area

$$\text{Area of division 1} = 1/2*(R_1)^2*Q \tag{1}$$

which is to equal to 1/10 of the area of the sector.

$$\text{Therefore, Area of division 1} = 1/10(1/2*(R_x)^2*Q) \tag{2}$$

Combining (1) and (2)

$$1/2*(R_1)^2*Q = 1/10(1/2*(R_x)^2*Q)$$

$$(R_1)^2 = 1/10*R_x^2$$

$$(R_1)^2/(R_x)^2 = 0.1 \tag{3}$$

$$R_1 = \sqrt{(0.1)}*R_x \tag{4}$$

$$\text{Area of division 2} = 1/2*(R_2)^2*Q - 1/2*(R_1)^2*Q$$

$$1/2*(R_2)^2*Q - 1/2*(R_1)^2*Q = 1/10(1/2*(R_x)^2*Q)$$

$$1/2*(R_2)^2*Q - 1/10(1/2*(R_x)^2*Q) = 1/10(1/2*(R_x)^2*Q)$$

$$1/2*(R_2)^2*Q = 1/10(1/2*(R_x)^2*Q) + 1/10(1/2*(R_x)^2*Q)$$

$$= 1/5(1/2*(R_x)^2*Q)$$

$$(R_2)^2/(R_x)^2 = 0.2 \tag{5}$$

$$R_2 = \sqrt{(0.2)}*R_x \tag{6}$$

$$\text{Area of division 3} = 1/2*(R_3)^2*Q - 1/2*(R_2)^2*Q$$

$$1/2*(R_3)^2*Q - 1/2*(R_2)^2*Q = 1/10(1/2*(R_x)^2*Q)$$

$$1/2*(R_3)^2*Q - \{1/10(1/2*(R_x)^2*Q) + 1/10(1/2*(R_x)^2*Q)\} = 1/10(1/2*(R_x)^2*Q)$$

Figure 3.2. An example of a sector divided into 10 equal areas.

$$1/2*(R_3)^2*Q = \{1/10(1/2*(R_x)^2*Q) + 1/10(1/2*(R_x)^2*Q)\} + 1/10(1/2*(R_x)^2*Q)$$

$$= 3/10*(1/2*(R_x)^2*Q)$$

$$(R_3)^2/(R_x)^2 = 0.3 \qquad (7)$$

$$R_3 = \sqrt{(0.3)}*R_x \qquad (8)$$

Thus the ratios of $((R_1)^2, (R_2)^2, (R_3)^2$, etc.) to $(R_x)^2$ are 0.1, 0.2, 0.3, etc. respectively. Thus area sampling can be changed to point sampling since each point on the radius represents an equal area of the sector.

In the sampling procedure adopted each of the six sectors selected randomly was divided into 100 not 10 equal areas and values R_1 to R_{100} calculated. Tabulations of these values enabled random selection from 100 equal areas by locating points along the radius.

An example of the proforma for a sampled sector with its percentage ratio for a log is shown in Appendix 5.

$$R_y = \sqrt{(y/100)}*R_x \qquad (9)$$

where R_y = distance between the end point of a division on the radius passed through the middle of that division and the center of the circle

y = percentage ratio

Because the shape of a log cross-section is never perfectly round the radius measured in one direction may differ from that measured in another direction. Therefore, the minimum radius was used. The selected points were sprayed with one of six different colours (blue, black, red, yellow, white and silver).

All sawn boards with paint sprayed during sector sampling were collected as they came off the green chain. They were then identified by tree and log number and colour of the paint which, of course, indicated the position of the board in the cross section of the log. Inspection through the length of a board was then done to determine where a 600 mm long clear specimen could be obtained. Defect free sawn boards were unusual (common defects were knots, pith, sloping grain and kino-vein). In sampling, those parts with defects were rejected. The number of 600 mm clear lengths per board was counted. When defects were numerous and severe, only three or four 600 mm lengths could be recovered.

Random numbers as one integer number from 1 to 2, 1 to 3, 1 to 4, up to 1 to 8 (the maximum number of defect free lengths that could be obtained from a board) were generated with a computer. These numbers were used in sampling through the length of a board. For example, if four 600 mm clear length were counted, a random number taken from those sampled from 1 to 4 was used to select the 600 mm length from the board to be used as a specimen.

The maximum number of 600 mm length that could be selected was 216 (6 x 4 x 9), 6 sectors in each log, 4 logs from each of 9 trees sampled. However, only 173 boards were obtained due to the severe defects occurring in some boards and, in some cases, the thickness of the board was insufficient to enable a 20 mm x 20 mm test specimen to be milled. The number of boards selected from each sawlog is listed in Table 3.3.

Table 3.3. Boards selected from 1939 regrowth E. regnans sawlogs from Toolangi, Victoria.

Log no.	Tree no.	Log code no.	Ht. at small end of log [m]	Small end diameter [mm]	No. of boards selected
1	1	0111	5.5	389	5
2		0112	11	355	4
3		0121	16.4	320	5
4		0122	20	290	3
5	2	0211	5.5	425	5
6		0212	11	415	3
7		0221	16.4	362	6
8		0222	21.8	314	3
9	3	0311	5.5	335	4
10		0312	11	320	4
11		0322	18.2	275	5
12		0323	21.8	255	4
13	4	0411	5.5	430	5
14		0412	11	400	5
15		0421	14.6	320	5
16		0423	21.8	255	6
17	5	0511	5.5	450	5
18		0512	11	415	4
19		0521	16.5	377	5
20		0522	22	342	5
21	6	0611	5.4	510	5
22		0612	10.8	460	6
23		0621	16.3	420	5
24		0622	21.7	370	5
25		0631	26.7	355	4
26	8	0811	5.4	430	6
27		0812	10.6	400	4
28		0831	25.2	302	6
29		0833	28.8	260	6
30	10	1011	5.4	480	5
31		1012	10.8	450	5
32		1031	27.2	315	2
33		1032	30.8	315	5
34	12	1211	5.5	505	6
35		1212	11	475	6
36		1231	25.1	460	6

3.4.1.3. Preparation of Test Specimens

Two standard sizes for small clear specimens are prescribed in Australian Standards for mechanical testing of timber, namely 20 x 20 mm and 50 x 50 mm. The required dimension, for the static bending test is 20 x 20 x 300 mm or 50 x 50 x 750 mm and for the compression parallel to the grain test, 20 x 20 x 60 mm or 50 x 50 x 200 mm (Mack, 1979). The 20 x 20 mm standard size was chosen for this study to limit the amount of material to be handled but also because the thickness of the green sawn boards was not, in general, large enough to enable 50 mm x 50 mm specimens to be prepared in the dry condition.

The small clear specimens were prepared in the Timber Engineering Workshop of the Forestry Department, ANU. Wherever possible, adjacent specimens were obtained for the green and dry tests. If only one specimen was obtainable, it was prepared for testing in the unseasoned condition. Unseasoned timber was dressed immediately to 20 x 20 mm. However, timber to be seasoned was cut to 35 x 35 mm to allow for shrinkage during drying and for dressing.

The unseasoned specimens were stored in a portable ice box to keep them permanently wet. The other specimens were stacked in the shade and air dried for 6 weeks to reduce moisture content before kiln drying and thus reduce collapse and surface checking which commonly occur in eucalypts in the initial stage of drying. Before stacking, the specimens were end coated with paraffin wax (Hercules 336) to prevent undesirable end-checking and end-splitting. After 5 weeks air drying, 5 sticks were selected to represent the stack and weighed every 24 hours to check the daily moisture reduction. The rate of air drying was slow at the end of 6 weeks with the moisture content of the 5 specimens ranging from 25 to 40 %. Although this range of moisture content may not be low enough to prevent end-checking and splitting, it was decided to stop air drying and use a very mild drying schedule in an experimental kiln at the Department of Forestry, A.N.U. The kiln drying took approximately fourteen days.

When the average moisture content of the specimens reached 12%, the specimens were reconditioned. The test specimens were then dressed to the required standard size.

In the preparation of test specimens from the Scottsdale timber, it was decided to obtain as many specimens as possible since the original number of boards available was only forty and because it was intended to investigate the variability in the test results by fitting different distributions to the results and predicting 1% probability values. Where only two length matched specimens could be obtained one was seasoned, the other left unseasoned. If three length matched specimens could be obtained the central specimen was seasoned; the two outside specimens were tested unseasoned. If four specimens were obtained, they were allocated alternately to both test conditions. The number of specimens prepared for each test is shown in Table 3.4.

Table 3.4. Test specimens prepared from timber of 1927 regrowth E. regnans from Scottsdale, Tasmania.

Test	Number of specimens	
	Unseasoned	Seasoned
Static bending	91	62
Compression parallel to the grain	91	62

In the preparation of the Toolangi timber it was not possible to obtain a pair of matched test specimens from each board because of the occurrence of defects such as gum veins and gum pockets because of drying defects such as internal checking, surface checking and unrecoverable collapse during seasoning. The number of specimens eventually prepared is shown in Table 3.5.

Table 3.5. Test specimens prepared from timber of 1939 regrowth E. regnans from Toolangi, Victoria.

Test	Number of specimens	
	Unseasoned	Seasoned
Static bending	167	115
Compression parallel to the grain	130	80

3.4.1.4. Mechanical Testing of Timber Specimens

Two kinds of test were undertaken; static bending and compression parallel to the grain. Static bending tests allowed the modulus of rupture and modulus of elasticity to be calculated, the compression parallel to the grain tests gave maximum crushing strength. All tests were done at the N.S.W. Forestry Commission laboratory at West Pennant Hills, to take advantage of automated testing procedures and because the laboratory is air conditioned to the standard conditions of 68% relative humidity and 15'C. The temperature range in the timber testing laboratory at the ANU was too great.

All specimens prepared from the Scottsdale wood were tested that is there were 91 values for each property in the unseasoned timber and 62 in the seasoned timber.

Not all specimens prepared from the Toolangi wood were tested, the number being a compromise between the precision required, the availability of test specimens and the time available for testing.

Pearson and Williams (1965) estimated the precision of results from mechanical testing as shown in Table 3.6.

Table 3.6. Precision of results from mechanical tests for strength properties

No. of trees	Number of specimens per tree	95% confidence half range [%][1]
9	1	9.5
9	2	8
9	5	7.3
9	20	6.5

Source - Pearson and Williams (1965)

The required precision, expressed as the 95% confidence half range of the species mean value for 1939 regrowth E. regnans was not accurately known. The confidence half range of the species mean value for MOR of mature E. regnans was calculated Table 3.7 using data in Bolza and Kloot (1963) and for the Scottsdale timber already tested in this study (See 3.4.2.1.1).

Table 3.7. Precision of results for MOR of mature E. regnans and for 1927 regrowth E. regnans from Scottsdale.

Statistic	Mature	Regrowth
Species mean [MPa]	63.2	52.6
95% Confidence half range [%]	6.2	7.2

Thus if the required confidence half range was determined as the same as for mature E. regnans i.e. 6.2 %, the number of specimens per tree would be about 24 and if the same as the 1927 regrowth E. regnans from Scottsdale, i.e. 7.2%, the number of specimens per tree would be 9. The number of specimens prepared from each log of Toolangi wood ranged from 2 to 6; the mean number of logs per tree was 4 and 9 trees were selected. Since the number of specimens tested should be spread evenly over the number of logs, it would be appropriate to select one or two specimens per log. One specimen per log, gives 4 specimens per tree; 36 specimens

1 See the definition in appendix 1.

for each test, if two per log than 72 specimens in all. If 4 specimens were tested from each tree the confidence half range for the species mean value was estimated as about 7.5%, with 8 specimens about 7%. It was decided to allocate the specimens into sets with one specimen per sawlog, giving a confidence half range of about 7.5 %, not much less than that of the 1927 regrowth E. regnans. Six specimens were not available from every log so that some sets did not include 36 specimens. The number of specimens in each set is shown in Table 3.8.

Table 3.8. The number of specimens in each set re-sampled randomly to give one specimen per log from 1939 regrowth E. regnans from Toolangi, Victoria.

Test	Moisture condition	Number of specimens					
		Set 1	Set 2	Set 3	Set 4	Set 5	set 6
Static Bending	green	36	36	35	32	20	8
	air dry	36	36	33			
Compression parallel to the grain	green	36	36	35	32	20	8
	air dry	36	36	33			

Mechanical testing for strength grouping was conducted with set number 1 which included 36 specimens for every kind of test. To provide a larger data set to analyse for variability in terms of MOR values 72 specimens of unseasoned timber and 115 of seasoned timber were tested.

3.4.1.4.1. Static Bending Test

Static bending tests were done on a SHIMADZU timber testing machine, set up according to the Australian standard testing method (See Plate 1, Mack (1979)). The span was 280 mm using centre point loading at a constant rate of movement of the load table. The machine was connected to a data recording and processing system and the results of the tests were computed immediately. The computer network included a plotting facility and a plot of load against deflection was drawn for every specimen as the tests proceeded. This was found very useful in checking for test results. Examples of the data print out are shown in Appendix 6.

The MOE values were measured first in batches. Specimen number, depth and width were typed into the data storage system. The specimen was positioned in the machine and a digital meter was set to measure the deflection due to load. Loading was continued to less than the limit of proportionality and then released. The modulus of elasticity was then calculated by the computer and printed out.

More tests were undertaken in batches after MOE tests. Before each specimen was tested, number, depth and width were again typed into the data storage system. The specimen was then positioned and testing begun. Load was applied until the specimen broke. The plotter drew a curve for load against deflection throughout the test. After each test the modulus of rupture was calculated by the computer and printed out.

The MOE and MOR tests were done separately for the following reasons:

(1) To avoid frequent removal of the digital meter.

(2) Separate computer programmes were involved.

(3) Plotting scales were different.

(4) To save time the MOR tests were all done at a test rate of approximately 3 mm per minute whereas the MOE tests were done at the standard rate of approximately 1 mm per minute.

The faster rate was adopted because hundreds of tests were envisaged to examine the variability of the wood at different sites, because there was limited time available for testing in the laboratories of the Forestry Commission of New South Wales in Sydney and because comparative results of material from the various sites and trees was a major interest. The practical effects of the faster rate were assumed to be small on the basis that the multiplication factors for duration of load, adopted in AS1720 1975, are 1.75 for both 5 second and 5 minute duration and 1.70 for 5 hours. The faster rate reduced the testing time from about 15 minutes to 5 minutes.

(5) The test configurations were also slightly different as shown in plates 3.1 and 3.2, and 3.3 and 3.4. Appendix 7.

3.4.1.4.2. Compression parallel to the grain test

The tests for compression parallel to the grain were done on an AVERY timber testing machine according to the Australian standard testing method. Movement of the testing head was at a constant rate of approximately 0.18 mm per minute. After each specimen was tested, the maximum crushing strength was immediately computed and printed out. The test configuration is shown in Plates 3.5 and 3.6. (Examples of the results are also shown in Appendix 8).

3.4.1.5. Moisture Content Determination

After completing the mechanical testing, test specimens were oven-dried and the moisture content of each specimen calculated. The test results were then adjusted to 12% M.C. The method of adjustment (AS 2878, 1986) is described in Appendix 3. Basic density and air dry density of each specimen were calculated.

3.4.2. RESULTS AND DISCUSSION

3.4.2.1. Strength Properties

3.4.2.1.1. Scottsdale Wood (1927 regrowth)

The mean, minimum, maximum, range, standard deviation, coefficient of variation (C.V) and standard error values for strength properties were calculated for both seasoned and unseasoned Scottsdale wood (Table 3.9). The mean values for all strength properties for both unseasoned and seasoned timbers are less than those for mature E. regnans as reported by Bolza and Kloot (1963). The C.V for strength properties of the unseasoned timber are less than those for the mature but the value for seasoned timber is higher. The C.V values also indicate that the inherent variability in the strength properties is higher in the seasoned timber.

Table 3.9. Values of the strength properties of timbers of 1927 regrowth E. regnans from Scottsdale, Tasmania.

Property	Moisture condition	Mean	Std. dev.	C.V [%]	Std. error	Min.	Max.	Range
MOR [MPa]	green	52.6	7.9	15.0	0.8	36.7	76.60	40.0
	dry	83.8	16.7	19.9	2.1	37.5	128.5	90.9
MOE [GPa]	green	10.5	1.9	18.1	0.2	5.6	15.3	9.8
	dry	12.6	2.6	20.4	0.3	7.0	18.0	11.0
MCS [MPa]	green	24.8	3.8	15.2	0.4	18.1	40.0	21.9
	dry	46.4	7.9	16.9	1.0	16.4	79.7	63.3
Basic Density [kg/m3]		486	73	15	7.7	359	714	354
Air Dry Density[kg/m3]		519	60	12	7.7	402	689	287

The percentage increases in the mean, minimum and maximum values, C.V and range of strength properties from green to dry, based on matched samples but regarding the green and dry material from the one species as two populations, are shown in Table 3.10. The relative increases from green to dry are not consistent.

Table 3.10. The increase in strength properties from green to dry condition for 1927 regrowth E. regnans from Scottsdale, Tasmania.

Property	Increase [%] (from green to dry)				
	Mean	Minimum	Maximum	C.V	Range
MOR	59.2	2.4	67.7	33.3	127.1
MOE	20.5	26.2	17.4	12.7	12.3
MCS	87.3	- 9.7	99.3	11.3	189.6

Using data from Bolza and Kloot (1963), the increases on drying in the strength properties of mature E. regnans can be compared with the results in Table 3.10. The comparison suggests that the increase in strength properties of the regrowth E. regnans from Scottsdale is less than that for the mature. In the regrowth, MOR increases 59.2% whilst the increase for the mature wood is 74.5%; MOE increases 20.5% whilst the increase for the mature wood is 26.6% and MCS increases 87.3% whilst that of the mature wood is 114%. Thus, the relative increase in the strength properties of the regrowth timber differs from that of the mature E. regnans.

Histograms of each strength property and basic and air dry densities for the Scottsdale wood are presented in Figures 3.3 to 3.6.

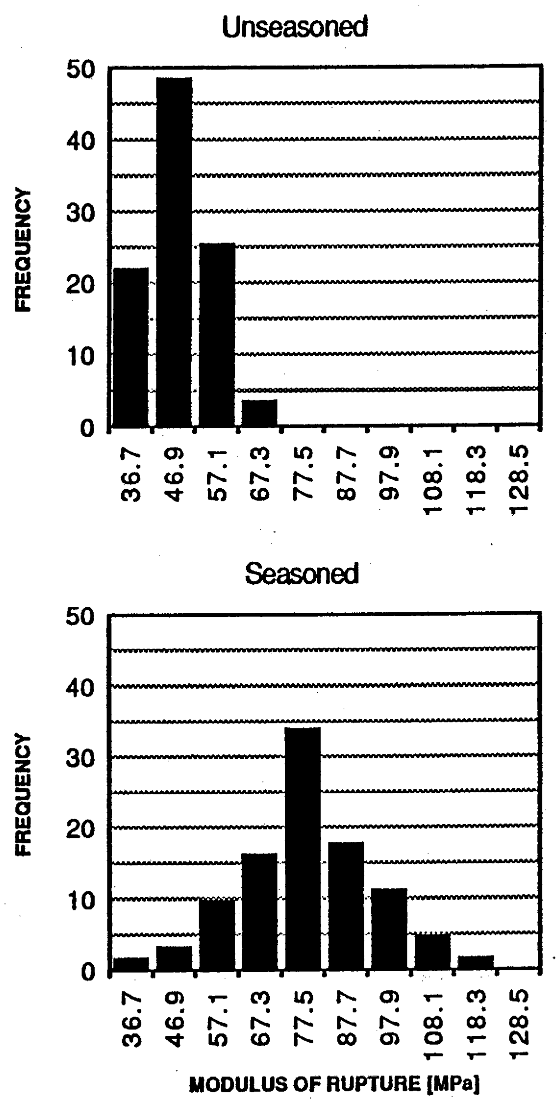


Figure 3.3. Distributions of MOR for 1927 regrowth from Scottsdale

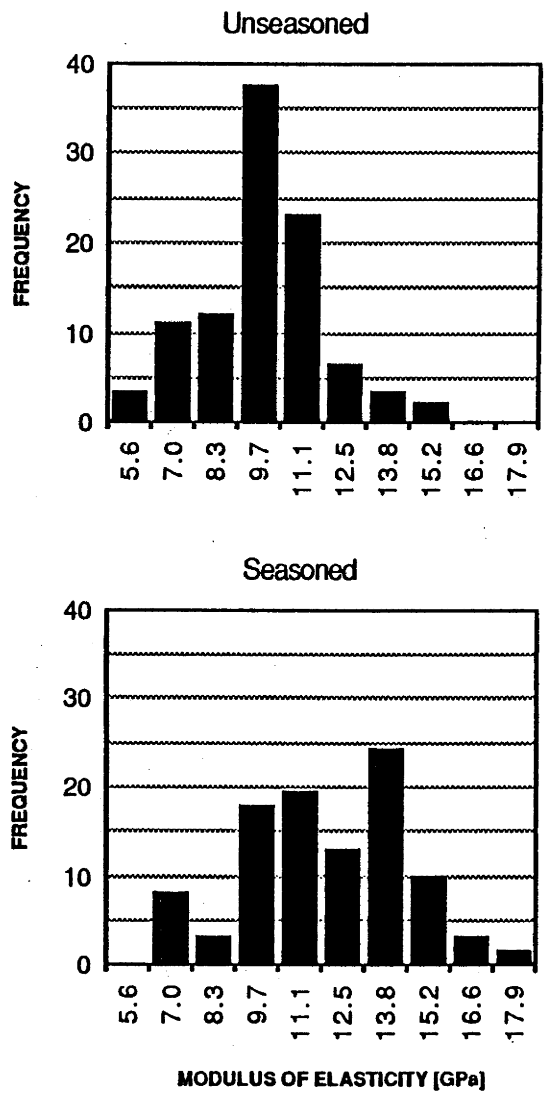


Figure 3.4. Distributions of MOE for 1927 regrowth from Scottsdale

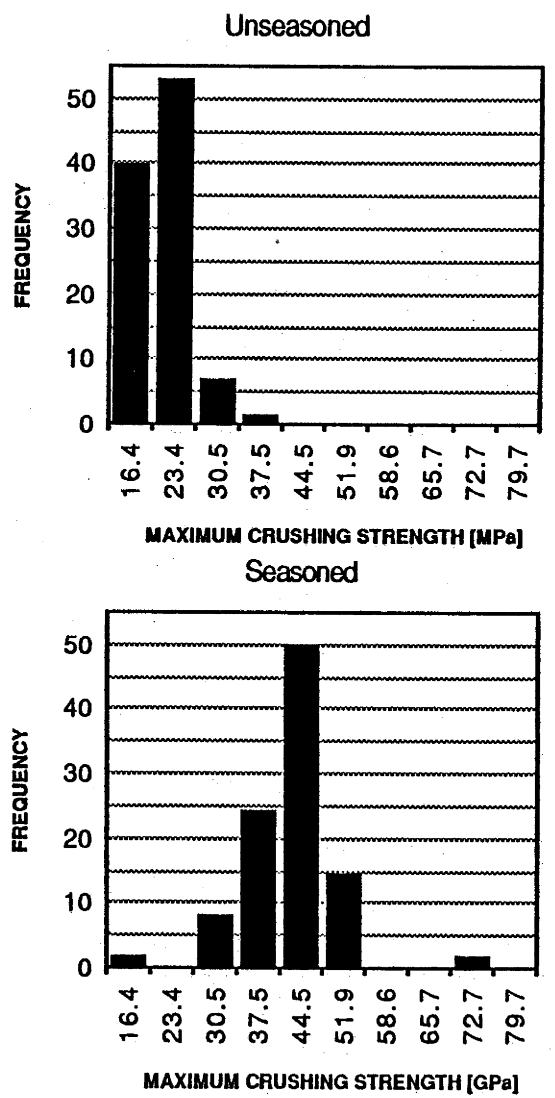


Figure 3.5. Distributions of MCS for 1927 regrowth from Scottsdale

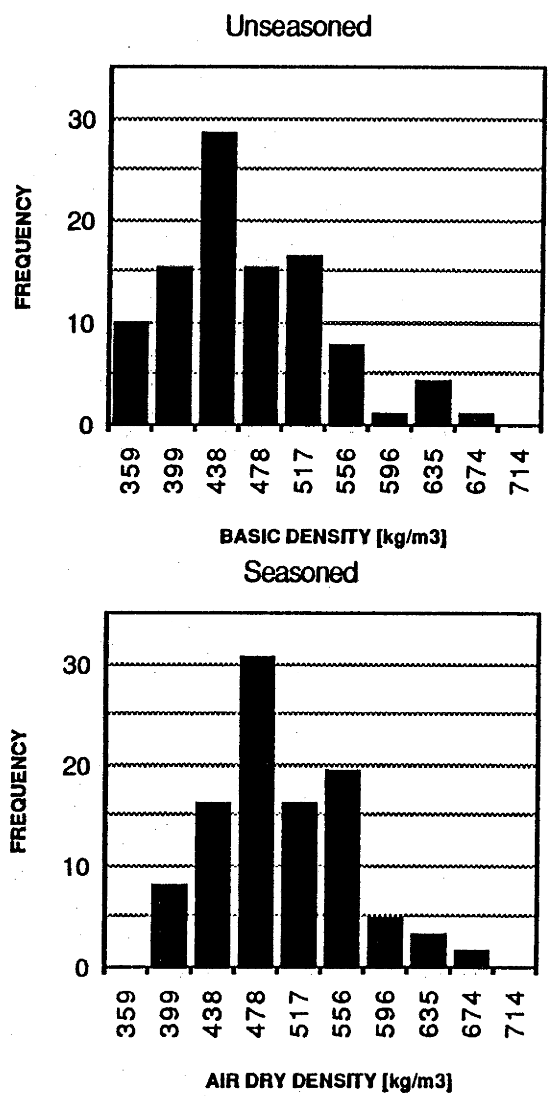


Figure 3.6. Distributions of basic and air dry density for 1927 regrowth from Scottsdale

The skewness and kurtosis values for each distribution are presented in Table 3.11. Figures 3.3 to 3.6 and Table 3.11 show that generally the distributions of strength properties deviate from normal. Sunley (1974), however, found a normal distribution of MOR based on the results of 2628 tests of Baltic redwood (Pinus sylvestris L.). He concluded that if only a few tests are made the individual results will appear to vary erratically, but as the number increases, a more normal distribution becomes apparent.

Table 3.11. Skewness and kurtosis values for the distributions of strength properties of small clear specimens of 1927 regrowth E. regnans from Scottsdale, Tasmania.

Property	moisture condition	Skewness	Kurtosis
MOR [MPa]	green	.56	.35
	dry	.00	.49
MOE [GPa]	green	.00	.33
	dry	- .22	- .43
MCS [MPa]	green	.73	1.64
	dry	.25	6.57
Basic Density [kg/m3]		.74	.49
Air Dry Density [kg/m3]		.30	- .05

The data sets for MOR values were analysed by the statistician. It was concluded that a log normal distribution fitted the data with significance at 95% level for the unseasoned and above 90% for seasoned.

The analysis of relationships between strength properties and small end diameter and height in the tree of the small ends of logs was carried out with the Spearman correlation test (Table 3.12). A regression analysis was also conducted (Figures 3.7 and 3.8). Height in the tree of the small ends of logs was used because while the log lengths were known the portion of the sample in the log was not.

Table 3.12. Test statistics and related levels of significance obtained by "Spearman correlation" tests investigating the association between strength properties and small end diameter and height of the small ends of logs in the tree for 1927 regrowth E. regnans from Scottsdale.

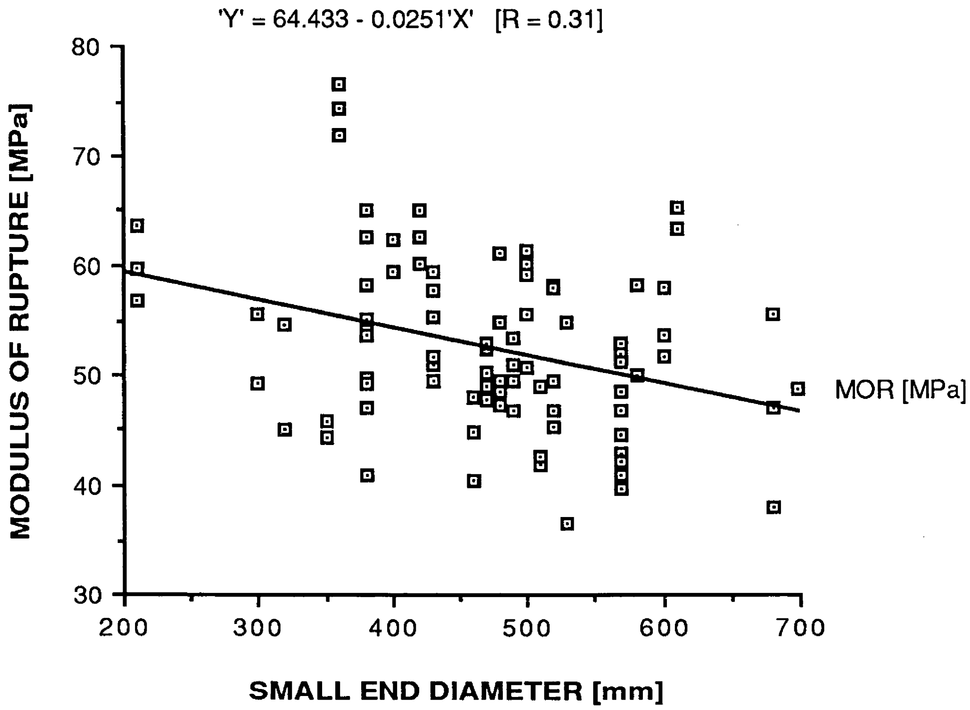
Variable 1	Variable 2	Number of observations	Test Statistic	Level of Significance
Unseasoned timber				
MOR	S. END D.	91	- 0.261	*
MOE	S. END D.	91	- 0.365	* *
MCS	S. END D.	91	- 0.314	* *
BD	S. END D.	91	- 0.376	* *
MOR	S. END HT.	91	0.064	ns
MOE	S. END HT.	91	0.291	* *
MCS	S. END HT.	91	0.013	ns
BD	S. END HT.	91	0.089	ns
Seasoned timber				
MOR	S. END D.	62	- 0.408	* *
MOE	S. END D.	62	- 0.463	* *
MCS	S. END D.	62	- 0.467	* *
ADD	S. END D.	62	- 0.501	* *
MOR	S. END HT.	62	0.424	* *
MOE	S. END HT.	62	0.391	* *
MCS	S. END HT.	62	0.354	* *
ADD	S. END HT.	62	0.385	* *

* = significant at 95%; ** = significant at 99%.

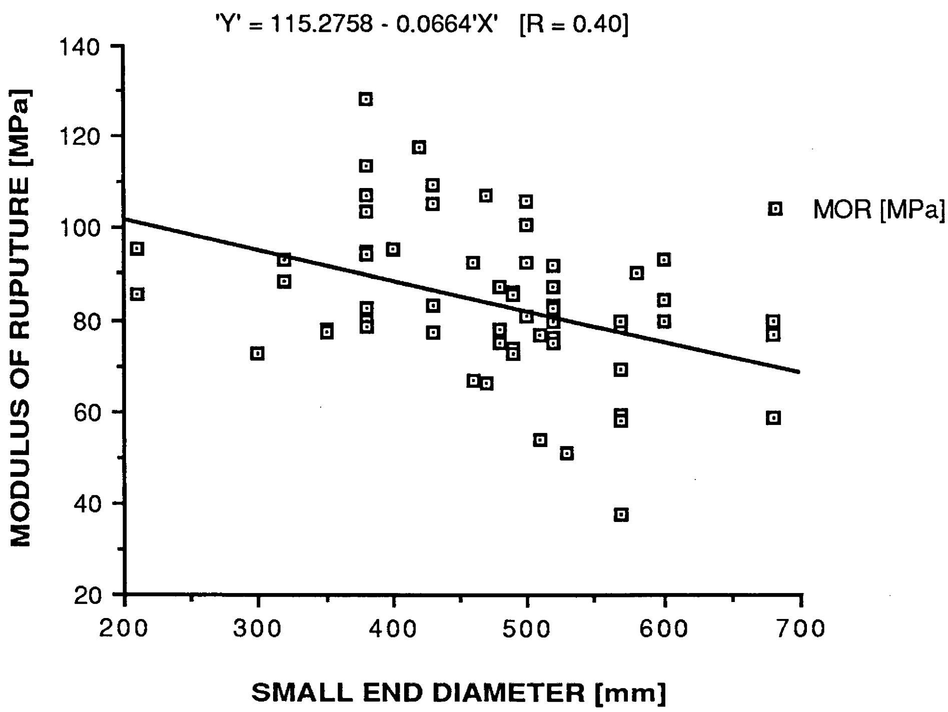
For unseasoned timber, associations (using Spearman correlation tests) between strength properties and small end diameter are significant; for MOR at the 95% level and for MOE, MCS and basic density at the 99% level. However, associations between strength properties and height within the tree at which the small ends of logs would have occurred are not significant except for MOE which is significant at the 99% level. The analysis suggests that for unseasoned timber from Scottsdale, strength properties are associated with small end diameter but not associated with height in the tree except for MOE.

However, the results of the regression analyses shown in Figures 3.7 and 3.8 suggest that there is only a weak trend in unseasoned clear specimens for the relationships between MOR and small end diameter and between MOR and height in the tree at which the small end of a log occurred ($r = 0.31$ and 0.11 respectively).

Figure 3.7. Relationship between MOR and small end diameter of log for small clear specimens from 1927 regrowth E. regnans from Scottsdale.

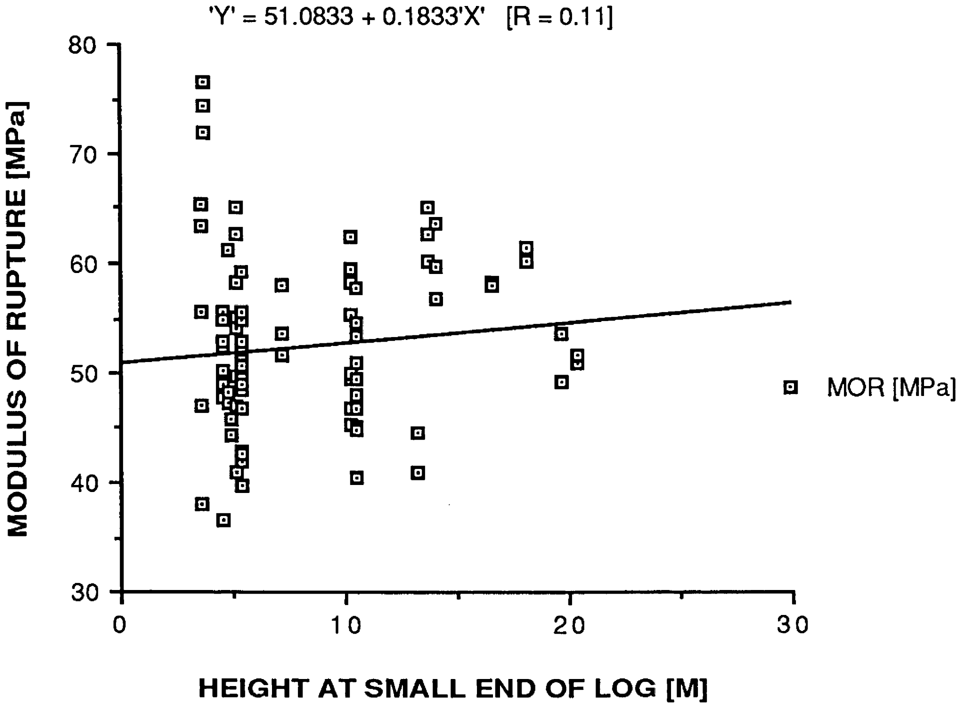


(1). Unseasoned timber

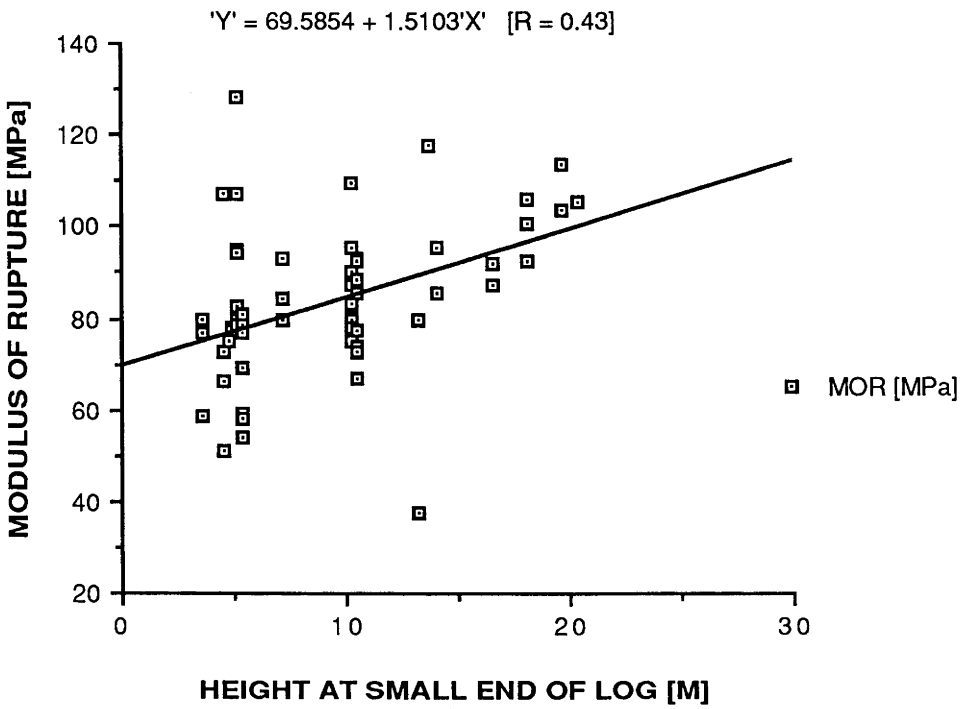


(2). Seasoned timber

Figure 3.8. Relationship between MOR and height at the small end of log for small clear specimens from 1927 regrowth E. regnans from Scottsdale.



(1). Unseasoned timber

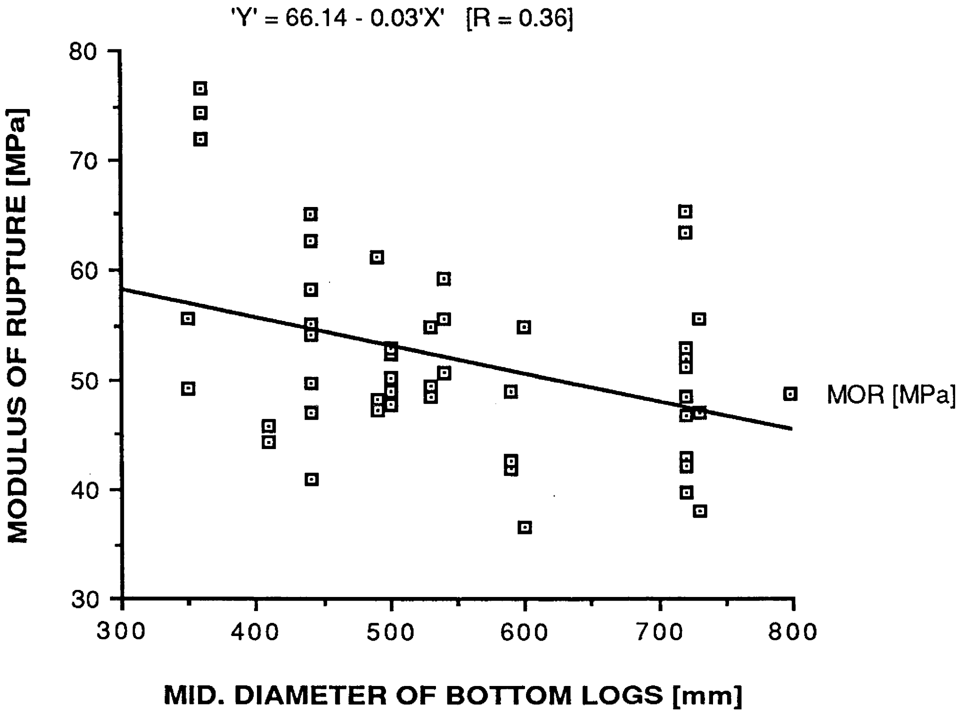


(2). Seasoned timber

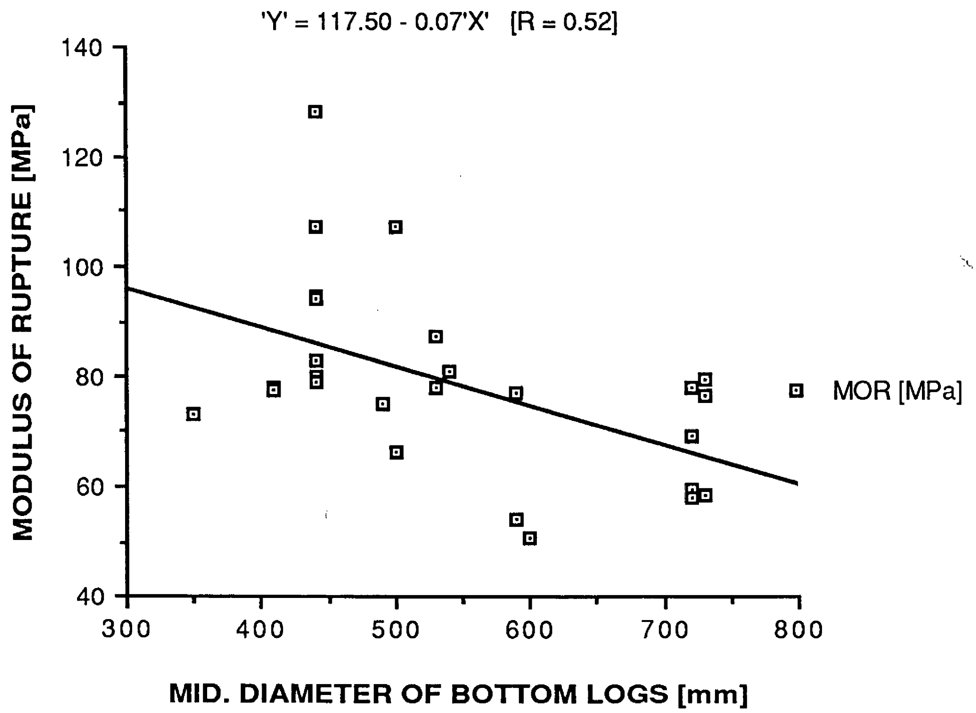
For seasoned timber, associations between strength properties and small end diameter and 'height' are highly significant (99% level) by the "Spearman correlation" test. Regression analysis suggests that MOR of seasoned small clear timbers of 1927 regrowth E. regnans from Scottsdale has a linear trend with both small end diameter and height in the tree of the small ends of logs, that is as with unseasoned timber MOR increases with a decrease in small end diameter and with increase in 'height'. However, the correlation coefficients for small end diameter and height respectively are only 0.40 and 0.43. In an even aged forest a strong correlation between strength properties and sawlog diameter would indicate a correlation with growth rate. However, for the timber tested, the strength properties are not convincingly related strongly to rate of growth here measured as diameter of logs from an even aged stand.

It has been shown the variability of regrowth wood is greater than for mature E. regnans. An easily measured parameter such as diameter at breast height in even aged forests and correlated with strength properties, might then assist in more efficient strength grouping of the wood. MOR values were, therefore, studied in relation to the mid diameter of the first log of each tree since the position of this diameter would be close to breast height. The relationship is shown in Figure 3.9. There is no strong correlation and it is concluded that diameter of the bottom log would not be a useful predict for classifying the wood in terms of strength properties.

Figure 3.9. Relationships between mid diameter of bottom logs and MOR of timber from 1927 regrowth stands at Scottsdale.



Unseasoned timber



Seasoned timber

Relations between MOR and other strength properties are also investigated for both unseasoned and seasoned timbers. The results are shown in Figures 3.10, 3.11, 3.12 and 3.13. The results are presented with MOR as the dependent variable as MOE and density can be measured nondestructively.

Figures 3.10 and 3.11 show the relationships between MOE and MOR, and MOE and MCS for unseasoned and seasoned timber. The correlation coefficients for unseasoned and seasoned timber are 0.78 and 0.84 for MOR and 0.53 and 0.75 for MCS respectively. From these we may conclude that MOE is well correlated with MOR and MCS.

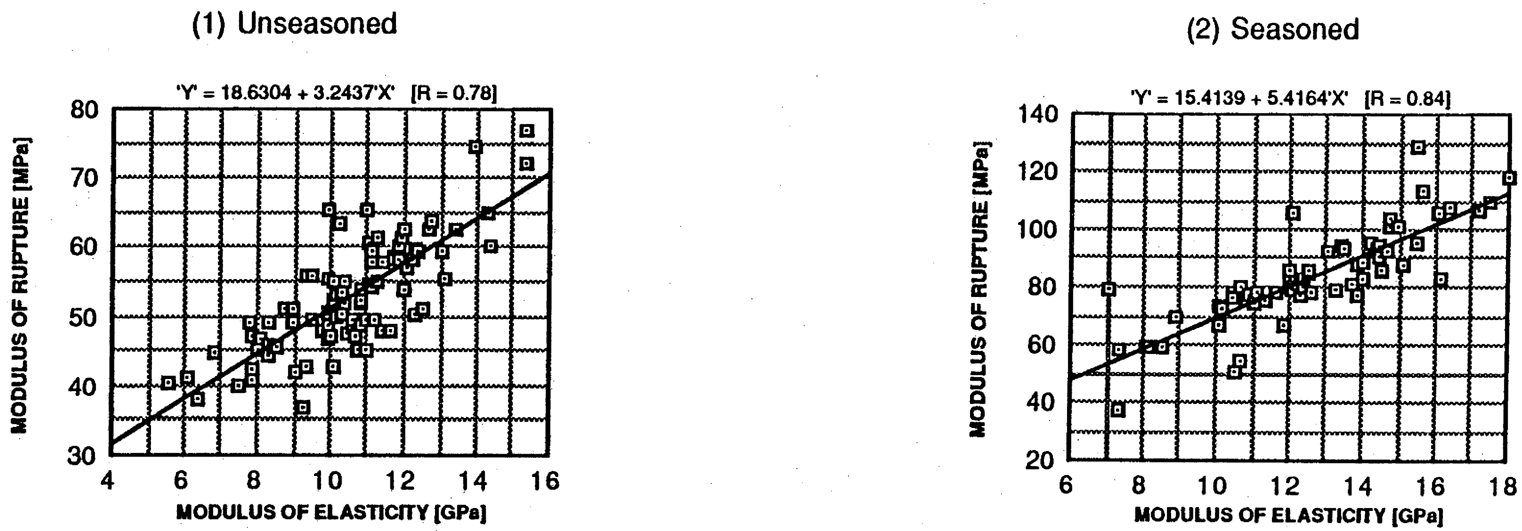


Figure 3.10. Relationships between MOE and MOR of unseasoned and seasoned timber of 1927 regrowth E. regnans from Scottsdale.

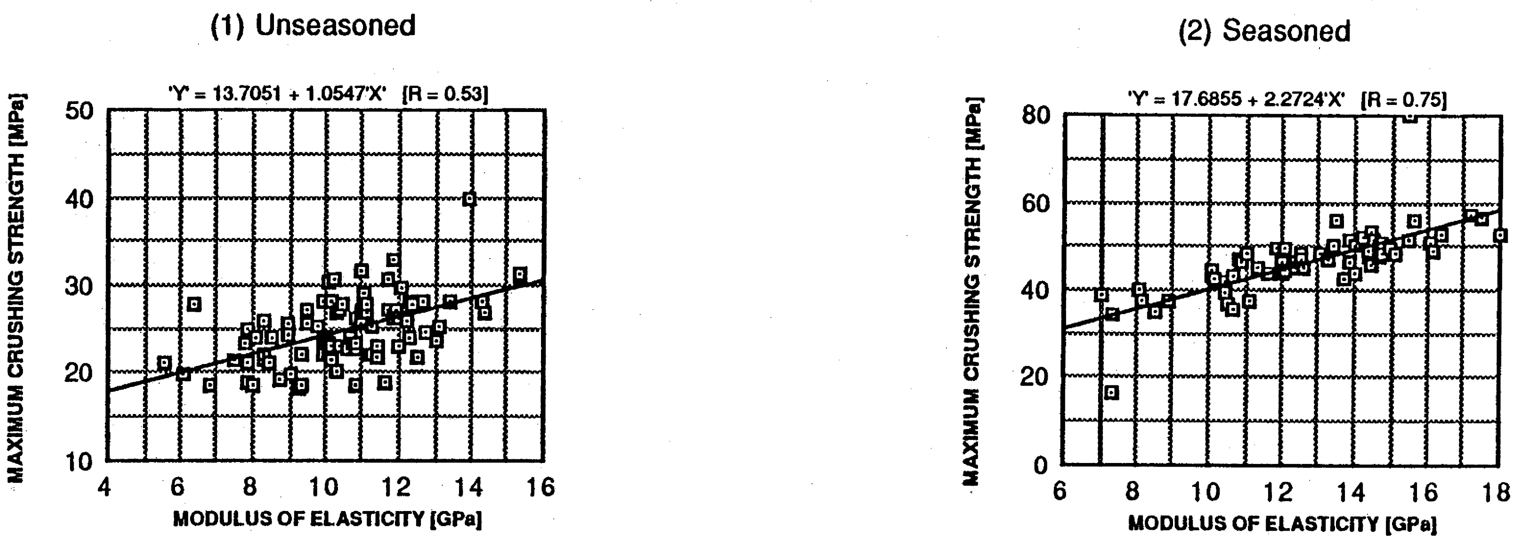


Figure 3.11. Relationships between MOE and MCS of unseasoned and seasoned timber of 1927 regrowth E. regnans from Scottsdale.

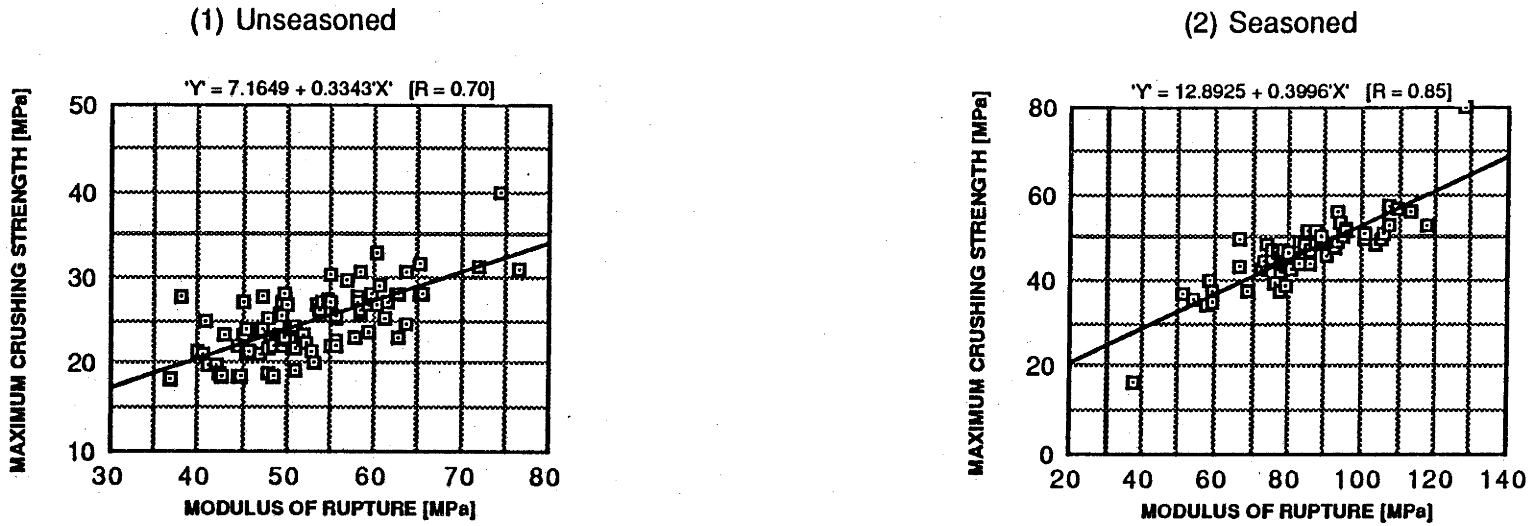


Figure 3.12. Relationships between MOr and MCS of unseasoned and seasoned timber of 1927 regrowth E. regnans from Scottsdale.

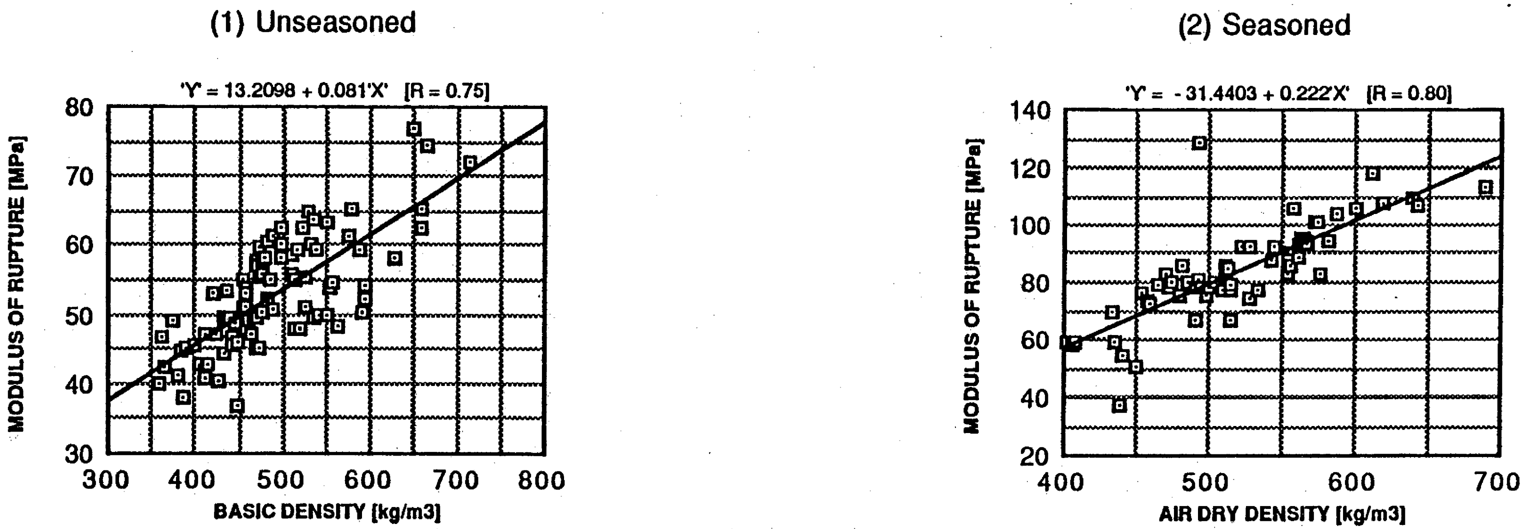


Figure 3.13. Relationships between MOR and basic and air dry density of timber of 1927 regrowth E. regnans from Scottsdale.

Figure 3.12 shows the relationships between MOR and MCS for unseasoned and seasoned timber. Here, MOR is taken as the independent variable to predict MCS. The correlation coefficients for unseasoned and seasoned timber are 0.70 and 0.85 respectively.

Figure 3.13 shows the relationships between MOR and basic density and air dry density. The correlation coefficients are 0.75 and 0.80 for basic density and air dry density respectively.

Figures 3.10 to 3.13 indicate relationships between strength properties and densities are highly significant in both unseasoned and seasoned wood. The strength of the correlations suggest that, as has been done for mature wood (see Table 2.2), stress grading could be a valid procedure in regrowth E. regnans.

3.4.2.1.2. Toolangi Wood (1939 regrowth)

A similar procedure to that used for Scottsdale wood was also used for Toolangi wood. The mean, minimum and maximum values, range, standard deviation, coefficient of variation and standard error values for the strength properties of small clear specimens of 1939 regrowth E. regnans from Toolangi, Victoria were determined. The results are presented in Table 3.13. The mean values of the strength properties for unseasoned timber are not significantly different from those for mature wood but the mean values of seasoned timber are less than those for mature. The C.V. values for unseasoned timber are close to those for mature wood but the C.V. values of seasoned timber are higher than for mature wood.

Table 3.13. Strength properties of timbers of 1939 regrowth E. regnans from Toolangi, Victoria.

Property	Moisture condition	Mean	Std. dev.	C.V [%]	Std. error	Min.	Max.	Range
MOR [MPa]	green	65.7	10.1	15.3	1.18	42.6	89.9	47.3
	dry	99.3	17.0	17.2	1.59	64.9	144.1	79.3
MOE [GPa]	green	12.1	1.9	15.9	.32	8.6	16.8	8.2
	dry	14.3	2.7	19.1	.45	8.6	19.3	10.7
MCS [MPa]	green	32.3	4.4	13.7	.74	24.4	42.2	17.8
	dry	49.0	9.2	18.8	1.96	34.7	64.5	29.8
Basic Density [kg/m3]		458	52.8	11.5	6.22	360	852	222
Air dry Density [kg/m3]		613	77.4	12.6	7.22	432	812	379

The percentage increases in the mean, minimum and maximum values of strength properties from the green to the dry condition, based on matched samples, are presented in Table 3.14. This shows that MOR and MCS of 1939 regrowth E. regnans timber from Toolangi increase similarly after seasoning but the increase in the C.V of MCS is about 3 times greater than that for MOR. Instead of increasing, the minimum decreases very slightly, that is 0.58%. The general increase in the range of the values is, however, noticeable. The increase in the C.V and the high relative increase in the range of properties show clearly that the timber of seasoned small clear specimens of 1939 regrowth E. regnans from Toolangi is more variable than for unseasoned timber.

Table 3.14. Change in strength properties from green to air dry of 1939 regrowth E. regnans from Toolangi.

Property	Increase [%] (green to dry)				
	Mean	Minimum	Maximum	C.V	Range
MOR	51.1	52.2	60.3	12.2	67.7
MOE	18.3	- 0.6	14.7	19.8	31.5
MCS	51.4	42.0	52.9	36.9	67.9

Using data from Bolza and Kloot (1963), the increases on drying in the strength properties of mature E. regnans can be compared with the results in Table 3.14. The increase in the mean strength properties of 1939 regrowth E. regnans from Toolangi is less than that for the mature. The MOR for 1939 regrowth increases 51.09%, for mature wood it is 74.48%; MOE increases 18.31 % for regrowth wood, for mature 26.60%; MCS increases 51.42% for regrowth wood, for mature 114%.

The minimum MOR of mature E. regnans increases 77 % on drying (Hurditch, 1987); the increase for 1939 regrowth E. regnans from Toolangi is only 52.19 %.

Histograms for strength properties for both unseasoned and seasoned timber tests are shown in Figures 3.14 to 3.17.

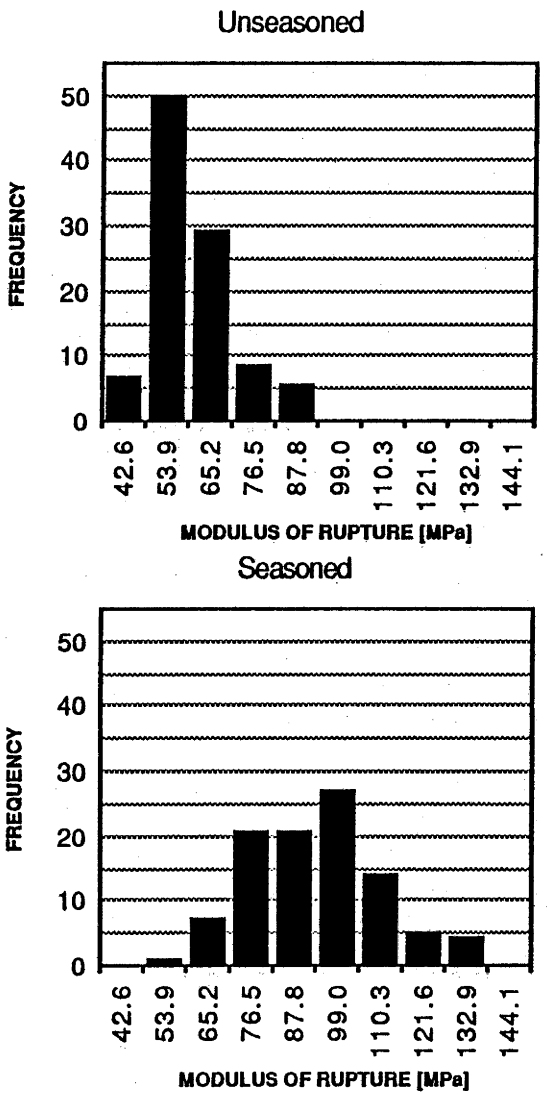


Figure 3.14. Distributions of MOR for 1939 regrowth from Toolangi

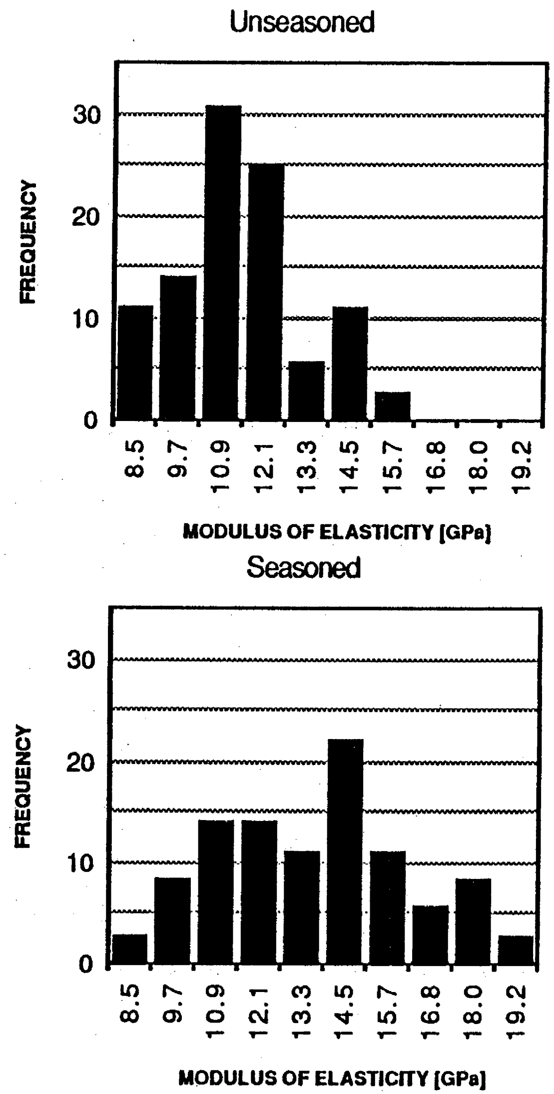


Figure 3.15. Distributions of MOE for 1939 regrowth from Toolangi

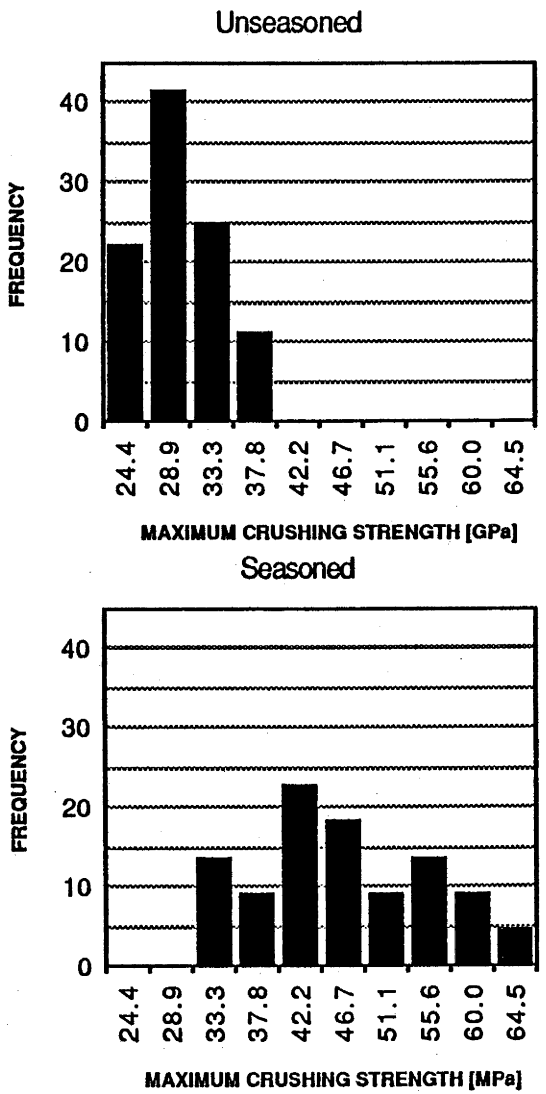


Figure 3.16. Distributions of MCS for 1939 regrowth from Toolangi

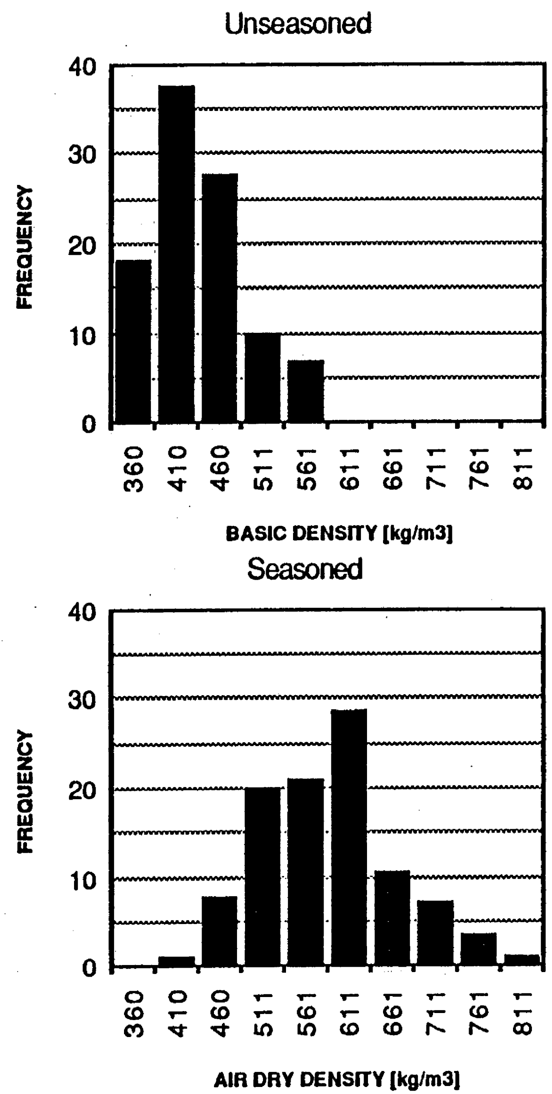


Figure 3.17. Distributions of Basic and air dry density for 1939 regrowth from Toolangi

The skewness and kurtosis values for each distribution are presented in Table 3.15. Figures 3.14 to 3.17 and Table 3.15 suggest the distributions of the properties are skewed and kurtosized. All distributions are positively skewed except for MOE of seasoned timber (as for Scottsdale wood). The MCS of unseasoned timber has the highest positive skewness; MCS of seasoned timber has the lowest. The kurtosis values for the distributions of strength properties are negative except for MOR of unseasoned timber. MCS of seasoned timber has the highest kurtosis value that for MCS of unseasoned timber the lowest. Thus the distributions of strength properties, as with the wood from Scottsdale, deviate from normal.

Table 3.15. Skewness and kurtosis values for the distributions of strength properties of small clear specimens of 1939 regrowth E. regnans from Toolangi.

Property	moisture condition	Skewness	Kurtosis
MOR [MPa]	green	0.649	0.156
	dry	0.322	-0.231
MOE [GPa]	green	0.357	-0.136
	dry	-0.064	-0.651
MCS [MPa]	green	0.673	-0.022
	dry	0.089	-1.003
Basic Density	[kg/m3]	0.594	-0.201
Air Dry Density	[kg/m3]	0.322	-0.274

The statistician, after analysing data, suggested that the distributions of MOR for unseasoned and seasoned timber are well fitted with a log normal distribution (significance level >95%).

An analysis was undertaken, using the same method as for the Scottsdale timber, to determine whether or not the strength properties are associated with small end diameter and with height in the tree of the small ends of logs. The results are presented in Table 3.16. A regression analysis was also undertaken. The results are shown in Figures 3.18 and 3.19.

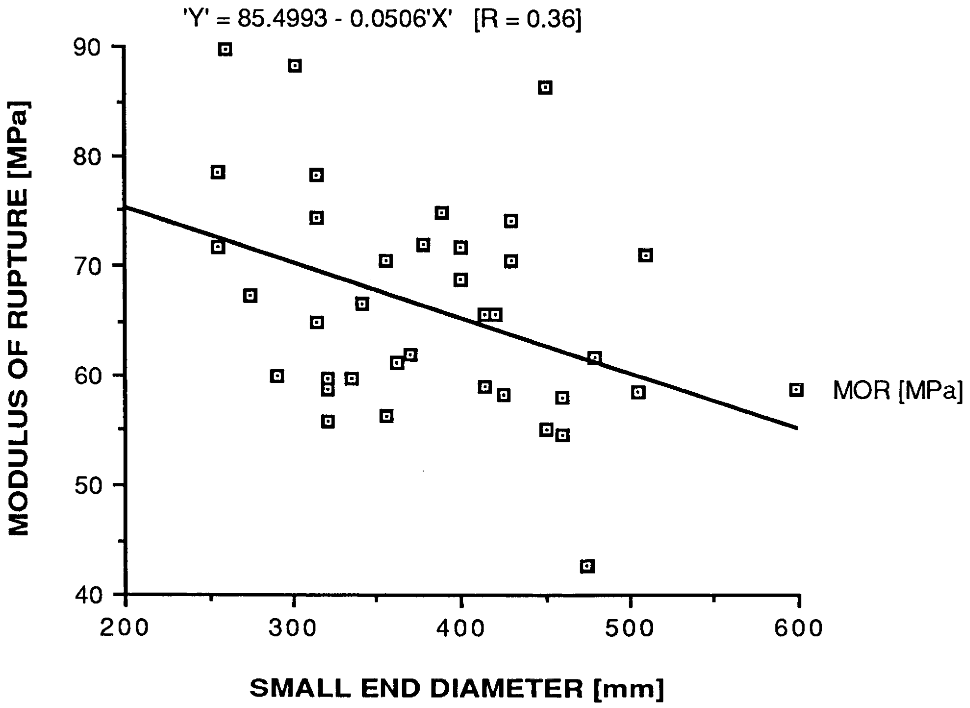
Table 3.16. Test statistics and related levels of significance obtained by "Spearman correlation" tests investigating the association between strength properties and small end diameter or height in the tree of the small ends of logs for 1939 regrowth E. regnans from Toolangi.

Variable 1	Variable 2	Number of observations	Test Statistic	Level of Significance
Unseasoned timber				
MOR	S. END D.	36	-0.269	ns
MOE	S. END D.	36	-0.297	ns
MCS	S. END D.	22	-0.227	ns
BD	S. END D.	36	-0.194	ns
MOR	S. END HT.	36	0.235	ns
MOE	S. END HT.	36	0.253	ns
MCS	S. END HT.	22	0.063	ns
BD	S. END HT.	36	0.127	ns
Seasoned timber				
MOR	S. END D.	36	-0.370	*
MOE	S. END D.	36	-0.141	ns
MCS	S. END D.	36	-0.158	ns
ADD	S. END D.	36	-0.105	ns
MOR	S. END HT.	36	0.244	ns
MOE	S. END HT.	36	0.202	ns
MCS	S. END HT.	36	0.200	ns
ADD	S. END HT.	36	0.158	ns

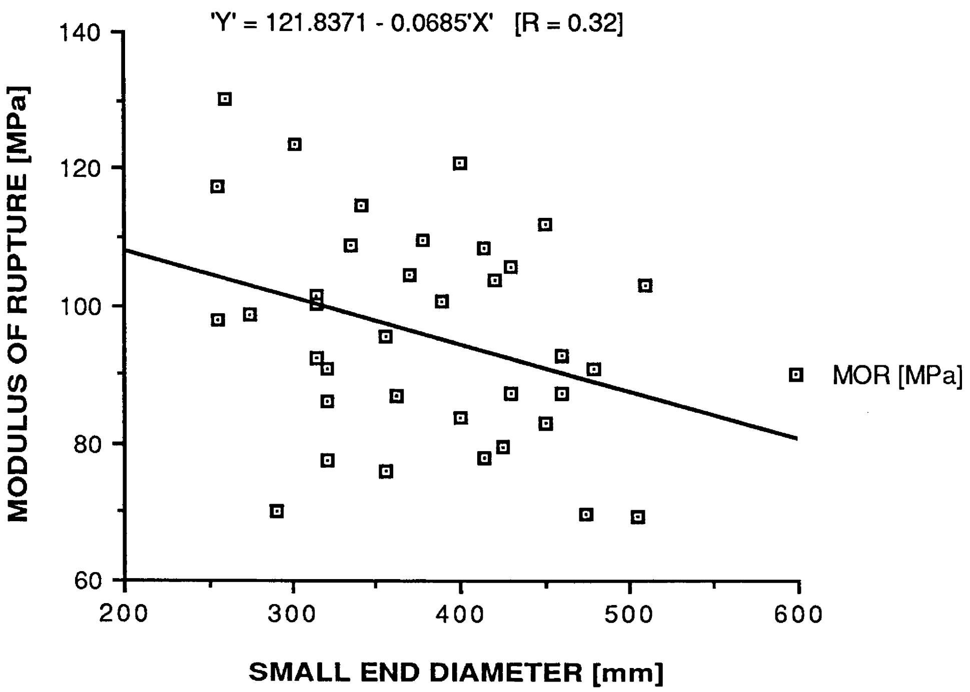
* = significant at 95%.

Apart from MOR and small end diameter in seasoned timber there are no significant correlations by the Spearman test. The regressions illustrated in Figure 3.18, presenting the relationship between MOR and small end diameter and in Figure 3.19, between MOR and height in the tree of the small ends of logs for unseasoned and seasoned small clear timbers of the 1939 regrowth E. regnans from Toolangi, Victoria suggest linear relationships. However, these relationships are not strong, the correlation coefficients for both small end diameter and 'height' are only 0.36 and 0.32, and 0.31 and 0.30 for unseasoned and seasoned timber respectively. Both 'Spearman' and regression analysis give similar results. Neither small end diameter nor 'height' could be used as a predictor to classify the regrowth timbers tested in terms of strength properties.

Figure 3.18. Regressions between MOR and small end diameter for unseasoned and seasoned small clear specimens of 1939 regrowth E. regnans from Toolangi.

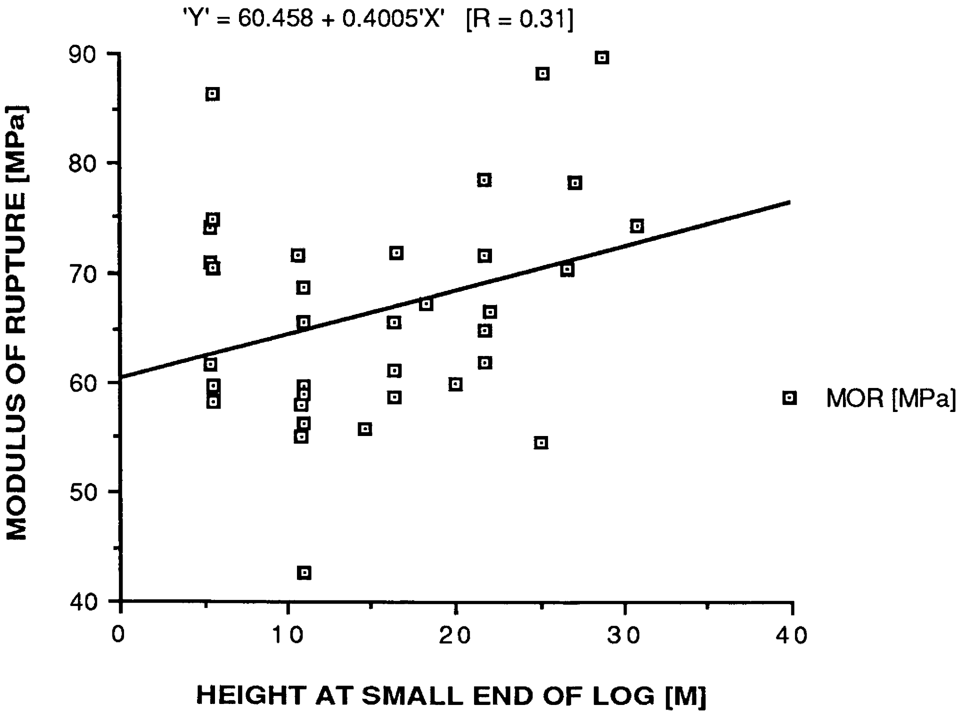


(1). Unseasoned timber

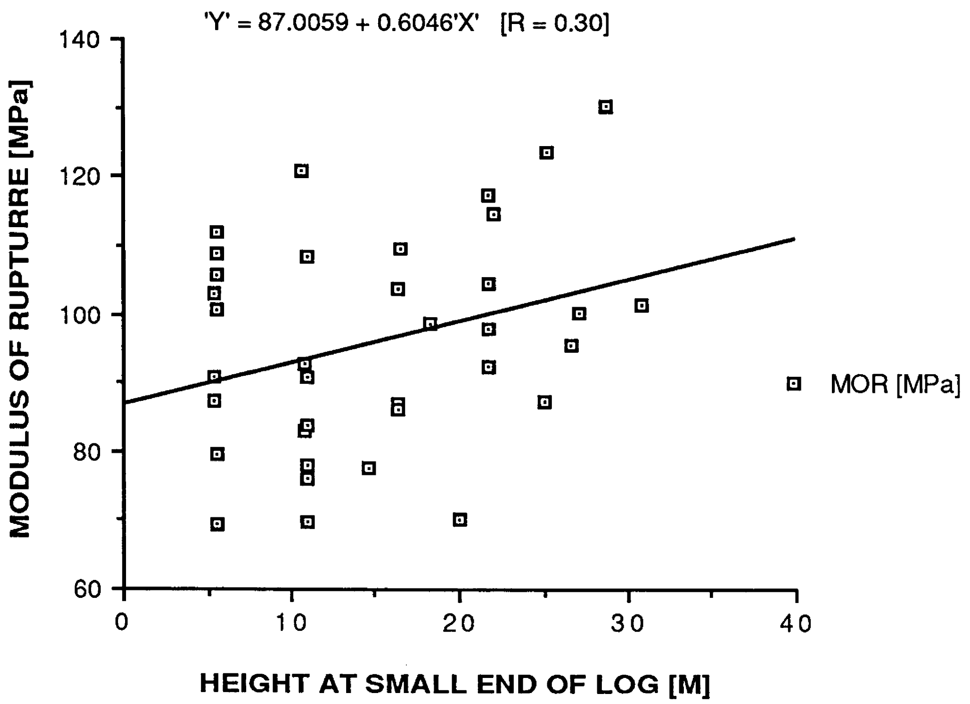


(2). Seasoned timber

Figure 3.19. Regressions between MOR and height at the small end of log for unseasoned small clear specimens of 1939 regrowth E. regnans from Toolangi.



(1). Unseasoned timber



(2). Seasoned timber

Relationships between MOR and other properties were also investigated by regression analysis. The results are illustrated in Figures 3.20 to 3.23.

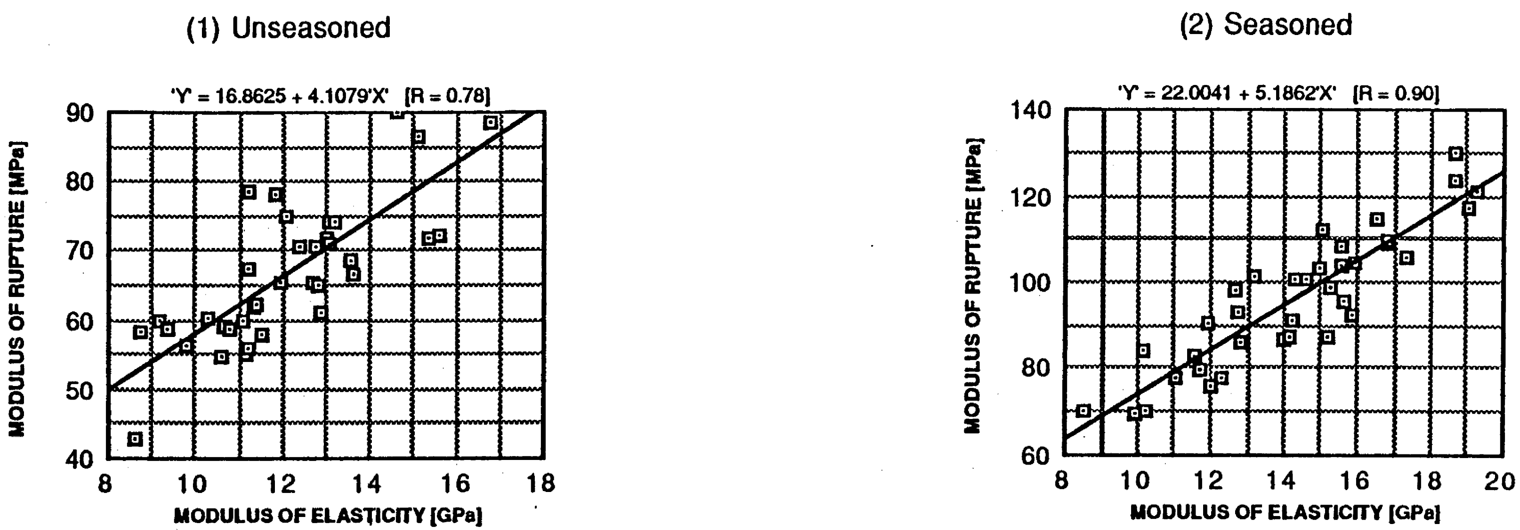


Figure 3.20. Relationships between MOE and MOR of unseasoned and seasoned timber of 1939 regrowth E. regnans from Toolangi.

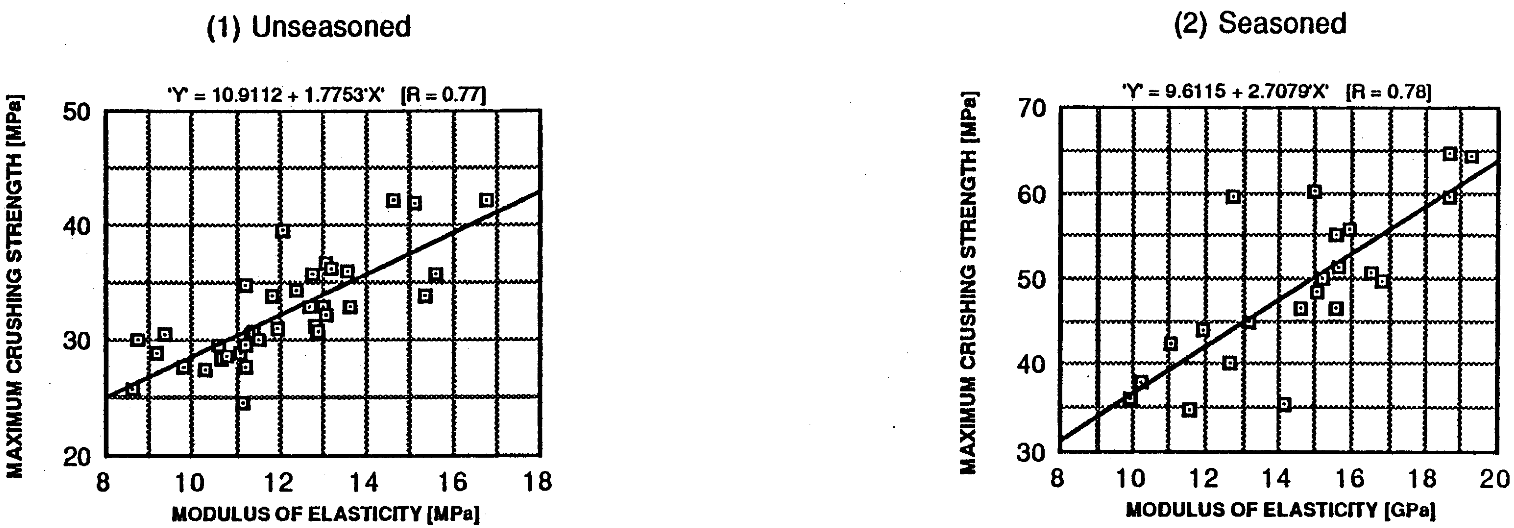


Figure 3.21. Relationships between MOE and MCS of unseasoned and seasoned timber of 1939 regrowth E. regnans from Toolangi.

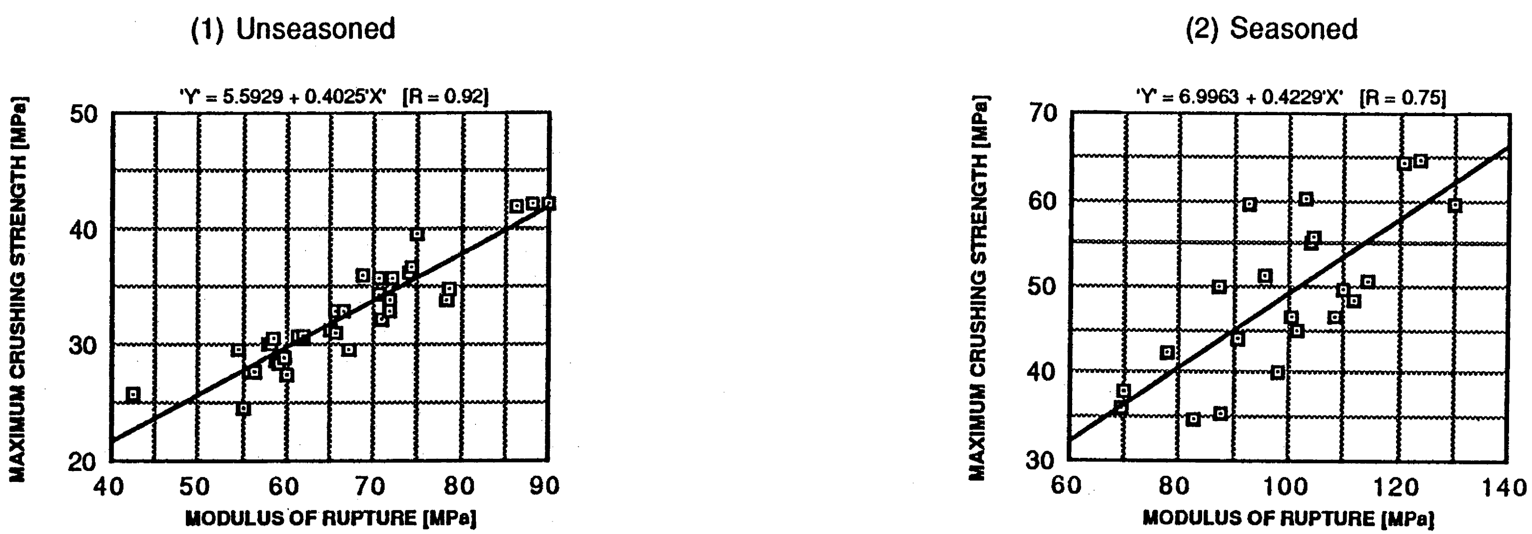


Figure 3.22. Relationships between MOR and MCS of unseasoned and seasoned timber of 1939 regrowth E. regnans from Toolangi.

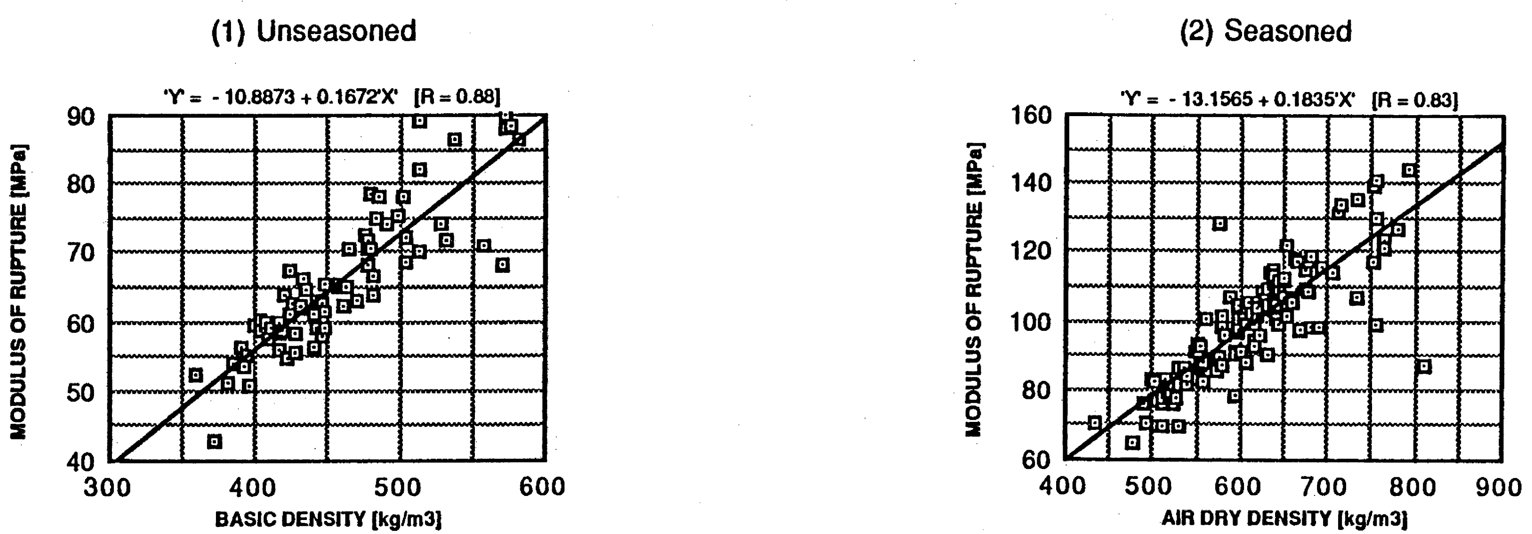


Figure 3.23. Relationships between MOR and basic and air dry density of timber of 1939 regrowth E. regnans from Toolangi.

Figures 3.20 and 3.21 indicate that MOE is highly correlated with both MOR and MCS for both unseasoned and seasoned timber, the correlation coefficients being 0.78 and 0.90 for MOR and 0.77 and 0.78 for MCS respectively.

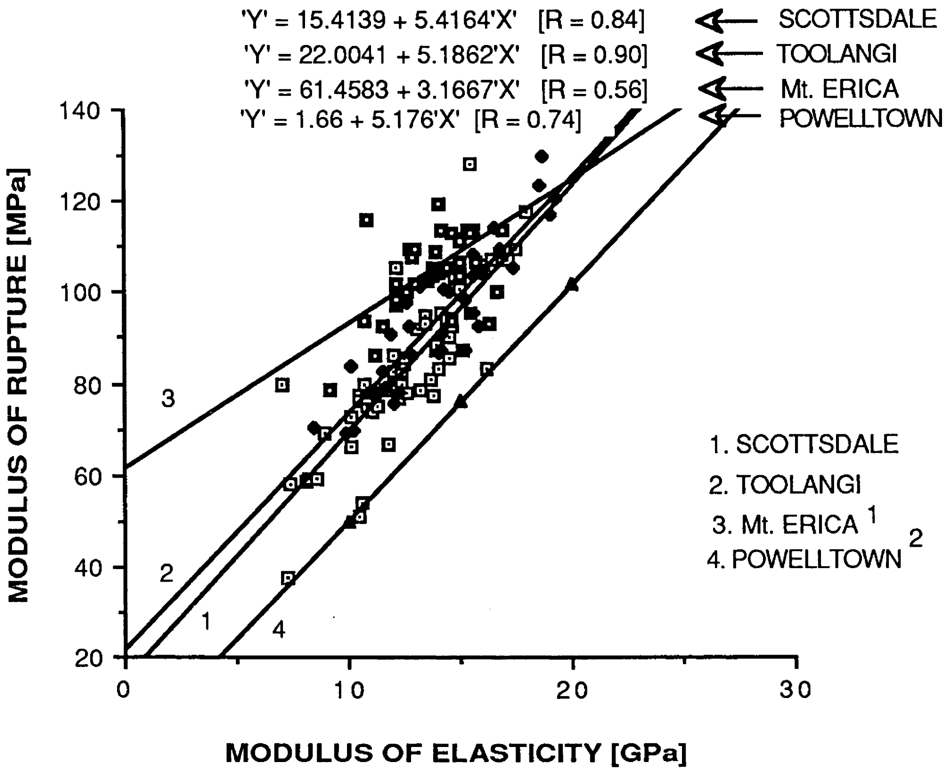
Figure 3.22 indicates that MOR is highly correlated with MCS for both unseasoned and seasoned timber, the correlation coeffecients being 0.92 and 0.75 respectively.

Figure 3.23 indicates that both basic density and air dry density are highly correlated with MOR with correlation coefficients of 0.88 and 0.83 respectively.

The properties examined and the relationships derived suggest that a grouping system can be applied to regrowth timbers. The significant relationship between MOE and MOR in both unseasoned and seasoned small clear specimens provides a good basis for a hypothesis that a strong relationship between these properties also occurs in structural size timber and that a machine stress grader may be practical for classifying structural timber in terms of its strength properties.

Regression lines for seasoned timbers from Scottsdale and Toolangi between MOE and MOR are shown in Figure 3.24 with that for 1939 regrowth from Mt. Erica (Breitinger, 1987) and one adopted for an experiment in machine stress grading of 1926 regrowth E. regnans from Powelltown (Anton, 1981).

Figure 3.24. Comparison of MOE MOR relationship between Scottsdale (Tasmania), Toolangi (Victoria), Mt. Erica (Victoria) and Powelltown (Victoria).



Notes 1 - After Breitinger (1987)
2 - After Anton (1981).

The regressions for Scottsdale and Toolangi timber are very similar. That for Mt. Erica timber has a much higher constant, a lower slope and a correlation coefficient of only 0.56. Estimates of MOR from measurements of MOE using the regressions will be very different at low MOE values. For example, with a measured value of MOE of 8 GPa MOR estimates would be 58.8 MPa for Scottsdale timber, 63.5 MPa for Toolangi, 39.8 MPa for Powelltown and 86.8 MPa for Mt. Erica. The regressions are so dissimilar that a machine stress grader may need to be reprogrammed according to the source of the timber.

3.4.2.2. Strength grouping of regrowth E. regnans from Scottsdale and Toolangi.

As described in Chapter 2, the strength properties required for grouping by the Australian grouping method (AS 2878, 1986) are MOR, MOE and MCS (positive strength grouping procedure) and density at 12% M.C (provisional strength grouping procedure). Data for both positive and provisional strength grouping were obtained in this study.

Table 3.17 gives results for positive strength grouping of wood from Scottsdale 1927 regrowth.

Table 3.17. Positive strength grouping of 1927 regrowth E. regnans from Scottsdale.

(a) Unseasoned timber

Property	Mean Value	Strength group
MOR [MPa]	52.6	S5
MOE [GPa]	10.5	S5
MCS [MPa]	24.8	S6
Strength group[1)]		S5

(b) Seasoned timber

Property	Mean Value	Strength group
MOR [MPa]	83.8	SD5
MOE [GPa]	12.6	SD5
MCS [MPa]	46.4	SD6
Strength group[1)]		SD5

1) AS2878, 1986 Clause 2.2.2

The final positive strength group is determined according to Australian Standard 2878 Clause 2.2.2 i.e. S5 and SD5 respectively.

Provisional strength grouping based on density at 12% moisture content (519 kg/m3) gave strength groups of (S7) and (SD8) for unseasoned and seasoned timber respectively a very conservative allocation compared to positive strength grouping.

Table 3.18 gives results for positive strength grouping of 1939 regrowth E. regnans from Toolangi.

Table 3.18. Positive strength grouping of 1939 regrowth E. regnans from Toolangi.

(a) Unseasoned timber

Property	Mean Value	Strength group
MOR [MPa]	69.7	S4
MOE [GPa]	12.1	S4
MCS [MPa]	32.3	S4
Positive strength group		S4

(b)Seasoned timber

Property	Mean Value	Strength group
MOR [MPa]	99.3	SD4
MOE [GPa]	14.3	SD4
MCS [MPa]	49.0	SD5
Positive strength group		SD4

Provisional strength grouping based on density at 12% moisture content (613 kg/m3) gave strength groups of (S6) and (SD7) for unseasoned and seasoned timber respectively, again a very conservative allocation compared to positive strength grouping.

For both Scottsdale and Toolangi timber, the provisional strength groups are at least two steps lower than those obtained by positive strength grouping.

The positive strength groups of regrowth E. regnans differ from both Scottsdale and Toolangi from those of mature E. regnans (Table 3.19).

Table 3.19. Strength groups of mature and regrowth E. regnans.

Locality	Strength group	
	Unseasoned	Seasoned
Mature*	S4	SD3
Regrowth		
Toolangi (1939)	S4	SD4
Scottsdale (1927)	S5	SD5

* - Australian Standard AS 2878 (1986)

The strength groups of the regrowth E. regnans from Toolangi and Scottsdale are lower than those of mature E. regnans except for unseasoned timber from Toolangi.

There is also evidence of strength group variations in 1939 regrowth E. regnans throughout Victoria (Table 3.20) The strength groups for unseasoned and seasoned regrowth timber from Mt. Erica are S5 and SD5 respectively, the strength group for unseasoned regrowth timber from Powelltown is S5 (Breitinger, 1986). The results of this study show that the strength group from Toolangi is one step higher than that from Mt. Erica and Powelltown regrowth.

Table 3.20. Strength groups for 1939 regrowth E. regnans from three localities in Victoria

Locality	Strength group	
	Unseasoned	Seasoned
Toolangi	S4	SD4
Mt. Erica[1)]	S5	SD5
Powelltown[1)]	S5	-

1) - After Breitinger (1987)

The strength group number of the regrowth E. regnans tested did not increase with drying, unlike mature E. regnans. The strength group for unseasoned timber from Scottsdale regrowth is S5, the strength group of seasoned timber is SD5. Similarly for Toolangi regrowth, the strength group for unseasoned timber is S4, that for seasoned timber is SD4. There are of course other timbers which do not have increase in strength group number when dried (for example after Australian Standard AS2878,1986 river red gum (E. camaldulensis) is strength grouped as S5, SD5 and Douglas fir (Pseudotsuga menziesii), as S6, SD6 for unseasoned and seasoned timber respectively). While rating the apparent difference between regrowth and mature timber it must be also noted that dry timber is regarded as a separate population in the development of strength groups, because of the inconsistent pattern shown by various species in drying from green.

The test results presented in this chapter show the strength properties of regrowth E. regnans are lower than those of mature E. regnans. Thus, if species remains the primary discriminator of strength properties for strength grouping the strength group of E. regnans should be reviewed to encompass the properties of the regrowth material.

On the other hand it would be feasible to specify groups for regrowth ash and mature ash separately. This question requires further consideration and is discussed in Chapter 4.

However the strength properties of regrowth E. regnans are very variable and strength group classification could be varied between sites. Setting aside questions of cost, practicality and quality control, a discriminator such as locality may assist in determining the strength group of regrowth E. regnans. Other properties discriminators such as age and small end diameter, however, have been shown to be of no value at this stage.

Further studies to establish the range in the strength properties of 1939 regrowth E. regnans from Victoria were, therefore, undertaken to enable further analysis of strength grouping for this material. These studies are reported in Chapters 5 and 6.

CHAPTER 4. STRENGTH GROUPING OF 1939 REGROWTH E. REGNANS IN VICTORIA

4.1. INTRODUCTION

Studies of timber from Toolangi (Chapter 3) showed the strength properties of 1939 regrowth E. regnans were lower than accepted values for mature E. regnans. These results were confirmed by data from other sources on Mt. Erica and Powelltown regrowth timber. In this Chapter studies to assess the variation in the strength groups of timber from even-aged stands of a much larger sample of 1939 regrowth E. regnans are reported.

4.2. MATERIALS AND METHODS

Wood was sampled from 1939 regrowth E. regnans at 4 sawmills[1] in Victoria.

1. Drouin West - logs from Mt. Erica and Noojee forest area
2. Powelltown - logs from Powelltown forest area
3. Murrindindi - logs from Murrindindi forest area
4. Marysville - logs from around Marysville.

It was not feasible to sample trees and undertake the felling, logging and delivery to mill of the sampled trees. However the butt logs from nine trees were sampled from each locality at the appropriate sawmill, that is 45 logs in all. Six boards were sampled from each log giving 54 boards from each locality and a total of 270 boards (Table 4.1).

The Toolangi studies had shown no strong relationship between strength properties and either small end diameter or 'height'; thus only butt logs were sampled since they were easy to identify.

---

1 See the location of sawmills in Appendix 8.

Table 4.1. Small end diameter of the butt log of trees of 1939 regrowth E. regnans from 5 localities in Victoria.

Locality	Sawmill	Log No.	Small end diam. [mm]	No. of boards
Powelltown	Powelltown Sawmill	1	518	6
		2	567	6
		3	600	6
		4	566	6
		5	531	6
		6	644	6
		7	655	6
		8	528	6
		9	742	6
Murrindindi	Murrindindi Sawmill	1	582	6
		2	572	6
		3	621	6
		4	678	6
		5	659	6
		6	548	6
		7	475	6
		8	415	6
		9	447	6
Marysville	Marysville Sawmill	1	643	6
		2	579	6
		3	521	6
		4	538	6
		5	594	6
		6	620	6
		7	642	6
		8	483	6
		9	395	6
Mt. Erica	Drouin West Sawmill	1	533	6
		2	688	6
		3	758	6
		4	544	6
		5	539	6
		6	528	6
		7	572	6
		8	447	6
		9	459	6
Noojee	Drouin West Sawmill	1	466	6
		2	455	6
		3	472	6
		4	436	6
		5	635	6
		6	567	6
		7	436	6
		8	439	6
		9	505	6

Sampling procedure and preparation of specimens were the same as for the Toolangi study (Chapter 3).

For the tests on unseasoned timber, 6 specimens were obtained from each of the nine logs. For seasoned timber 6 specimens could not be obtained from each log due to drying defects (Table 4.2).

Table 4.2. Number of test specimens prepared from 1939 regrowth E. regnans from 5 localities in Victoria.

Locality	Condition	Type of test	
		Static bending [MOR & MOE]	Compr. || grain [MCS]
Powelltown	unseasoned	54	54
	seasoned	47	47
Murrindindi	unseasoned	54	54
	seasoned	45	45
Marysville	unseasoned	54	54
	seasoned	50	50
Mt. Erica	unseasoned	54	54
	seasoned	46	46
Noojee	unseasoned	54	54
	seasoned	51	51

The strength tests were again carried out in the engineering laboratory of the NSW Forestry Commission at West Pennant Hills, Sydney.

To ensure the same precision the same number of specimens as at Toolangi were tested from each of the five localities that is 36 test specimens per locality were required. The test specimens were, therefore, sorted into six sets with one specimen from each of the 9 logs from each locality for unseasoned timber. Set 6 was not complete for seasoned timber since some material had to be rejected because of severe defect. Only sets 1, 2, 3 and 4 were, in fact selected to give the required 36 specimens per locality so that sets 5 and 6 were rejected 'in toto'(Table 4.3).

Table 4.3. The number of test specimens in each set resampled randomly with one specimen from each log.

Strength test	Moisture condition	Number of specimens					
		Set 1	Set 2	Set 3	Set 4	Set 5	Set 6
<u>Powelltown</u>							
Static bending	unseas.	9	9	9	9	9	9
	seas.	9	9	9	9	9	2
Compr. || G	unseas.	9	9	9	9	9	9
	seas.	9	9	9	9	9	2
<u>Murrindindi</u>							
Static bending	unseas.	9	9	9	9	9	9
	seas.	9	9	9	9	9	-
Compr. || G	unseas.	9	9	9	9	9	9
	seas.	9	9	9	9	9	-
<u>Marysville</u>							
Static bending	unseas.	9	9	9	9	9	9
	seas.	9	9	9	9	9	5
Compr. || 6	unseas.	9	9	9	9	9	9
	seas.	9	9	9	9	9	5
<u>Mt. Erica</u>							
Static bending	unseas.	9	9	9	9	9	9
	seas.	9	9	9	9	9	1
Compr. || G	unseas.	9	9	9	9	9	9
	seas.	9	9	9	9	9	1
<u>Noojee</u>							
Static bending	unseas.	9	9	9	9	9	9
	seas.	9	9	9	9	9	6
Compr. || G	unseas.	9	9	9	9	9	9
	seas.	9	9	9	9	9	6

Test specimens were subsequently dried and the basic and air dry densities calculated. The results for the seasoned specimens were adjusted to 12% M.C.

4.3. RESULTS AND DISCUSSION

4.3.1. INITIAL BASIC STUDIES OF STRENGTH PROPERTIES

The descriptive statistics for the strength properties and densities were calculated. The mean, standard deviation, C.V, standard error, minimum, maximum and range of values were calculated for each locality (Table.4.4).

Table 4.4. Properties of 1939 regrowth mountain ash from 5 localities in Victoria

Stat -istics	Strength Property																			
	Powelltown				Murrindindi				Marysville				Mt. Erica				Noojee			
	MOR	MOE	MCS	BD/ADD	MOR	MOE	MCS	BD/ADD	MOR	MOE	MCS	BD/ADD	MOR	MOE	MCS	BD/ADD	MOR	MOE	MCS	BD/ADD
Unseasoned condition																				
Mean	61.2	11.5	27.6	459	63.0	11.9	28.2	452	66.3	12.6	30.1	478	60.0	11.3	27.2	438	63.9	11.8	29.1	469
Std. dev.	7.7	1.8	3.7	46.2	8.0	2.2	4.2	40.5	6.9	2.1	4.0	39.0	8.6	2.0	4.2	49.9	7.8	1.9	3.1	43.7
C.V (%)	12.6	15.5	13.3	10.1	12.7	18.1	14.9	9.0	10.5	16.8	13.1	8.2	14.4	17.9	15.5	11.4	12.2	16.3	10.8	9.3
Std. error	1.29	0.30	0.61	7.70	1.33	0.36	0.70	6.75	1.15	0.35	0.66	6.50	1.44	0.34	0.70	8.31	1.30	0.32	0.52	7.29
Min.	40.9	7.0	18.5	351	42.8	6.9	17.6	357	48.7	6.0	20.4	396	45.3	7.7	18.9	356	45.2	6.6	23.9	386
Max.	73.6	15.2	36.7	524	75.3	15.7	34.8	521	76.3	15.6	36.1	556	82.9	17.7	37.2	596	79.6	15.0	37.4	565
Range	32.7	8.3	18.2	173	32.5	8.8	17.2	164	27.6	9.6	15.7	159	37.6	10.0	18.3	240	34.4	8.3	13.5	179
Seasoned condition																				
Mean	102.2	14.7	52.7	633	97.8	13.9	49.4	581	100.1	14.1	53.1	604	91.8	13.3	46.4	568	99.7	13.7	49.6	606
Std. dev.	13.4	2.1	6.0	57.7	12.5	2.0	5.9	57.2	9.6	2.1	5.5	42.9	16.4	2.4	9.9	76.0	15.7	2.7	7.1	61.8
C.V (%)	13.1	14.3	11.3	9.1	12.8	14.1	12.0	9.8	9.6	15.0	10.4	7.1	17.9	17.8	21.4	13.4	15.7	19.6	14.4	10.2
Std. error	2.23	0.35	1.00	9.62	2.09	0.33	0.99	9.53	1.60	0.35	0.92	7.15	2.73	0.39	1.66	12.67	2.61	0.45	1.19	10.30
Min.	70.1	10.5	36.7	513	67.9	9.3	33.6	442	84.3	9.1	43.5	528	53.8	8.8	30.6	451	62.8	6.0	33.1	449
Max.	129.0	20.0	63.0	735	118.4	18.0	62.1	671	118.9	17.3	66.2	698	130.5	18.1	84.6	803	125.7	18.7	64.8	711
Range	58.9	9.5	26.3	222	50.5	8.7	28.5	230	34.6	8.2	22.8	169	76.7	9.3	54.1	352	62.9	12.7	31.7	262

BD = Basic density for unseasoned timber

ADD = Density at 12% M.C for seasoned timber

MOR and MCS in MPa

MOE in GPa

For unseasoned timber the mean values for MOR varied from 60.0 to 66.3 MPa, the minimum from Mt. Erica, the maximum from Marysville. For seasoned timber these mean values varied from 91.8 to 102.2 MPa, the minimum again from Mt. Erica, the maximum from Powelltown.

For unseasoned timber the mean values for MOE varied from 11.3 to 12.6 GPa, the minimum from Mt. Erica the maximum from Marysville. For seasoned timber these mean values varied from 13.3 to 14.7 GPa, the minimum again from Mt. Erica the maximum from Powelltown.

For unseasoned timber the mean value for MCS varied from 27.2 to 30.1 MPa; for seasoned timber from 46.4 to 53.1 MPa for seasoned timber the minimum and maximum from Mt. Erica and Marysville respectively in both cases.

The mean value for basic density varied from 438 kg/m^3 from Mt. Erica to 478 kg/m^3 from Marysville. The mean value for air dry density varied from 568 kg/m^3 from Mt. Erica to 633 kg/m^3 from Powelltown.

The statistics indicate timber from Mt. Erica is lowest in strength and density for both seasoned and unseasoned conditions; timber from Marysville is the highest in strength and density in the unseasoned condition that from Powelltown is the highest in the seasoned condition.

A one way analysis of variance (Mendenhal, 1983) was undertaken to investigate the differences in properties between the 5 localities (Table 4.5). There are significant differences between localities, except for MOE. The difference for MOR is significant at the 95% level for both unseasoned and seasoned conditions; that for MCS at the 95% and 99% levels for unseasoned and seasoned conditions respectively. The difference for basic and air dry density is significant at the 99% level.

UNSEASONED TIMBER

Modulus of Rupture [MPa]

Source	D.F	SSE	MS	F	SL
Locality	4	864.44	216.11	3.53	*
Errors	175	10725.50	61.29		
Total	179	11589.94			

Modulus of Elasticity [GPa]

Source	D.F	SSE	MS	F	SL
Locality	4	36.57	9.14	2.29	ns
Errors	175	700.24	4.00		
Total	179	736.81			

Maximum Crushing Strength [MPa]

Source	D.F	SSE	MS	F	SL
Locality	4	204.47	51.12	3.45	*
Errors	175	2592.55			
Total	179	2797.02			

Basic Density [kg/m3]

Source	D.F	SSE	MS	F	SL
Locality	4	32951.21	8237.80	4.31	* *
Errors	175	334454.31	1911.17		
Total	179	367405.52			

SEASONED TIMBER

Modulus of Rupture [MPa]

Source	D.F	SSE	MS	F	SL
Locality	4	2284.57	571.14	3.04	*
Errors	175	32919.86	188.11		
Total	179	35204.42			

Modulus of Elasticity [GPa]

Source	D.F	SSE	MS	F	SL
Locality	4	41.16	10.29	2.04	ns
Errors	175	881.98	5.04		
Total	179	923.14			

Maximum Crushing Strength [MPa]

Source	D.F	SSE	MS	F	SL
Locality	4	1095.76	273.94	5.48	* *
Errors	175	8746.09	49.98		
Total	179	9841.85			

Air dry Density [kg/m3]

Source	D.F	SSE	MS	F	SL
Locality	4	91264.26	22816.07	6.33	* *
Errors	175	631273.90	3607.28		
Total	179	722538.16			

Note - '*' = sigificant at 95%; '**' = significant at 99%; and 'ns' = non significant.

Table 4.5. One way analysis of the differences between selected properties of 1939 regrowth E. regnans from 5 localities.

UNSEASONED TIMBER

Modulus of Rupture

Locality	N	E	G	M
P	ns	ns	* *	ns
M	ns	ns	ns	
G	ns	* *		
E	*			

Modulus of Elasticity

Locality	N	E	G	M
P	ns	ns	*	ns
M	ns	ns	ns	
G	ns	* *		
E	ns			

Maximum Crushing Strength

Locality	N	E	G	M
P	ns	ns	* *	ns
M	ns	ns	*	
G	ns	* *		
E	*			

Basic Density

Locality	N	E	G	M
P	ns	*	ns	ns
M	ns	ns	*	
G	ns	* *		
E	* *			

SEASONED TIMBER

Modulus of Rupture

Locality	N	E	G	M
P	ns	* *	ns	ns
M	ns	ns	ns	
G	ns	* *		
E	*			

Modulus of Elasticity

Locality	N	E	G	M
P	*	* *	ns	ns
M	ns	ns	ns	
G	ns	ns		
E	ns			

Maximum Crushing Strength

Locality	N	E	G	M
P	ns	* *	ns	*
M	ns	ns	*	
G	*	* *		
E	*			

Air Dry Density

Locality	N	E	G	M
P	ns	* *	*	* *
M	ns	ns	ns	
G	ns	*		
E	* *			

Note1 - P = Powell Town; M = Murrindindi; G = Marysville (Gould sawmill);
E = Mt. Erica; N = Noojee.
Note 2- '*' = sigificance at 95%; '**' = significance at 99%; and 'ns' = no significance.

Table 4.6. Analysis of the strength properties of 1939 regrowth E. regnans from 5 localities in Victoria by Least Significance Difference [LSD].

To establish differences between individual localities an analysis was undertaken using the Least Significant Difference [LSD] method. The results are presented in Table 4.6. There are no significant differences between unseasoned from Mt. Erica and Murrindindi nor between the seasoned timber from these locations. However, there are some significant differences between Mt. Erica timber and that from Powelltown, Marysville and Noojee respectively, for example between Mt. Erica and Powelltown, both density values and all the strength properties of seasoned timber; between Mt. Erica and Marysville, both density values and all the strength properties of unseasoned timber; between Mt. Erica and Noojee, both density values, both MOR and MCS of unseasoned timber. Although one way analysis shows no significant difference in MOE between localities, the LSD test indicates differences between Mt. Erica and Marysville for unseasoned timber and between Mt. Erica and Powelltown for seasoned timber.

Table 4.7. The Percentage increase in strength properties of 1939 regrowth from 5 localities in Victoria after drying.

Property	Mean	Min.	Max.	% Range	C.V %	Std. err.
Powelltown						
MOR	67.2	71.3	75.2	7.8	3.4	72.9
MOE	27.8	50.3	31.1	- 10.1	- 7.8	16.7
MCS	91.2	98.7	71.8	- 24.4	- 14.7	63.9
Murrindindi						
MOR	55.1	58.7	57.3	0.2	1.2	57.1
MOE	16.7	35.4	14.7	- 1.5	- 21.8	- 8.3
MCS	75.5	91.2	78.4	- 5.8	- 19.4	41.4
Marysville						
MOR	51.2	73.1	55.9	- 17.0	- 8.1	39.1
MOE	11.9	51.5	10.4	- 24.1	- 10.8	0
MCS	76.3	113.2	83.6	- 17.7	- 20.9	39.4
Mt. Erica						
MOR	53.0	18.8	57.4	33.1	24.2	89.6
MOE	17.6	14.9	2.2	- 21.4	14.7	- 0.5
MCS	70.7	62.0	127.3	72.8	38.3	137.1
Noojee						
MOR	56.0	38.8	57.9	17.3	29.3	100.8
MOE	16.4	- 9.2	25.0	30.8	20.1	40.6
MCS	70.3	38.8	73.6	38.1	33.5	128.9

Referring back to Table 4.4 the variation in the mean values for the strength properties of seasoned timber from the 5 localities are slightly higher than accepted values for mature ash. The coefficients of variation of the mean values for MOR range from 9.6% (Marysville) to 17.9 % (Mt. Erica) with an overall mean of 13.3%, while that for the mature is 11.5%. The coefficients of variation of the mean values for MOE range from 14.1% (Murrindindi) to 19.6% (Noojee) with an overall mean of 16.1%, while that for the mature is 14.8 %. The coefficients of variation of the mean values for MCS range from 10.4% (Marysville) to 21.4 % (Mt. Erica) with an overall average of 13.9%, while that for the mature is 12.3 %.

However, the variability of the overall mean value for MOR of unseasoned timber is lower in comparison with the mature ash; for MOE slightly lower and for MCS slightly higher. The coefficients of variation of the mean values for MOR of unseasoned timber range from 10.5 (Marysville) to 14.4 % (Mt. Erica) with an overall mean of 12.5% while that for the mature is 15.3%. The coefficients of variation of the mean value for MOE range from 15.5% (Powelltown) to 18.1% (Murrindindi) with an overall mean of 16.89%, while that for the mature is 17.5%. The coefficients of variation of the mean values for MCS range from 13.1% (Marysville) to 19.6% (Noojee) with an overall mean of 13.5 % while that for the mature is 12.5%.

Generally the variability in the strength properties of seasoned timber of 1939 regrowth E. regnans is higher than that of the unseasoned timber.

The increase in the strength properties of 1939 regrowth after seasoning from the five localities is less than for mature ash (Table 4.7) except for MOE of timber from Powelltown.

Table 4.8. Skewness and kurtosis values for strength properties of 1939 regrowth from 5 localities in Victoria.

Locality	Property	Moisture condition	Skewness	Kurtosis
Powelltown	MOR	green	- 0.547	- 0.118
		dry	- 0.422	- 0.262
	MOE	green	- 0.340	- 0.051
		dry	0.452	0.047
	MCS	green	- 0.326	0.706
		dry	- 0.508	0.060
	Basic Density		- 0.891	- 0.042
	Air dry Density		- 0.348	- 0.723
Murrindindi	MOR	green	- 0.890	0.231
		dry	- 0.272	-0.638
	MOE	green	- 0.343	- 0.672
		dry	0.223	- 0.303
	MCS	green	- 0.556	- 0.520
		dry	- 0.070	- 0.006
	Basic Density		- 0.369	- 0.770
	Air dry Density		- 0.217	- 0.837
Marysville	MOR	green	- 0.469	- 0.632
		dry	0.117	- 0.028
	MOE	green	-1.051	1.232
		dry	- 0.304	- 0.854
	MCS	green	- 0.432	- 0.714
		dry	0.424	- 0.336
	Basic Density		- 0.317	- 0.829
	Air dry Density		0.247	- 0.980
Mt. Erica	MOR	green	0.530	- 0.107
		dry	0.367	0.005
	MOE	green	0.716	0.936
		dry	- 0.091	- 0.641
	MCS	green	0.447	- 0.115
		dry	1.532	3.924
	Basic Density		0.799	0.891
	Air dry Density		0.881	0.709
Noojee	MOR	green	- 0.072	- 0.106
		dry	- 0.302	- 0.764
	MOE	green	- 0.186	- 0.297
		dry	- 0.647	0.160
	MCS	green	0.631	- 0.117
		dry	- 0.218	- 0.547
	Basic Density		0.288	- 0.545
	Air dry Density		- 0.429	- 0.491

Skewness and kurtosis values for each distribution of strength properties were also calculated (Table 4.8)(Figures 4.1 to 4.4). The histograms and the skewness and kurtosis values suggest that none of the distributions approaches normal. However, the pattern of deviation from normal is not consistent. For example, while the distributions of the MOR values for seasoned timber from Powelltown, Murrindindi and Noojee are negatively skewed those from Marysville and Mt. Erica are positively skewed.

The pattern of deviation from normal for strength properties is also not consistent between matched samples of unseasoned and seasoned timbers. For example, while the distribution of MOR of unseasoned timber from Marysville is negatively skewed, the distribution of MOR of seasoned timber is positively skewed.

Figure 4.1. Histograms of modulus of rupture of unseasoned and seasoned timber of 1939 regrowth E. regnans from Victoria.

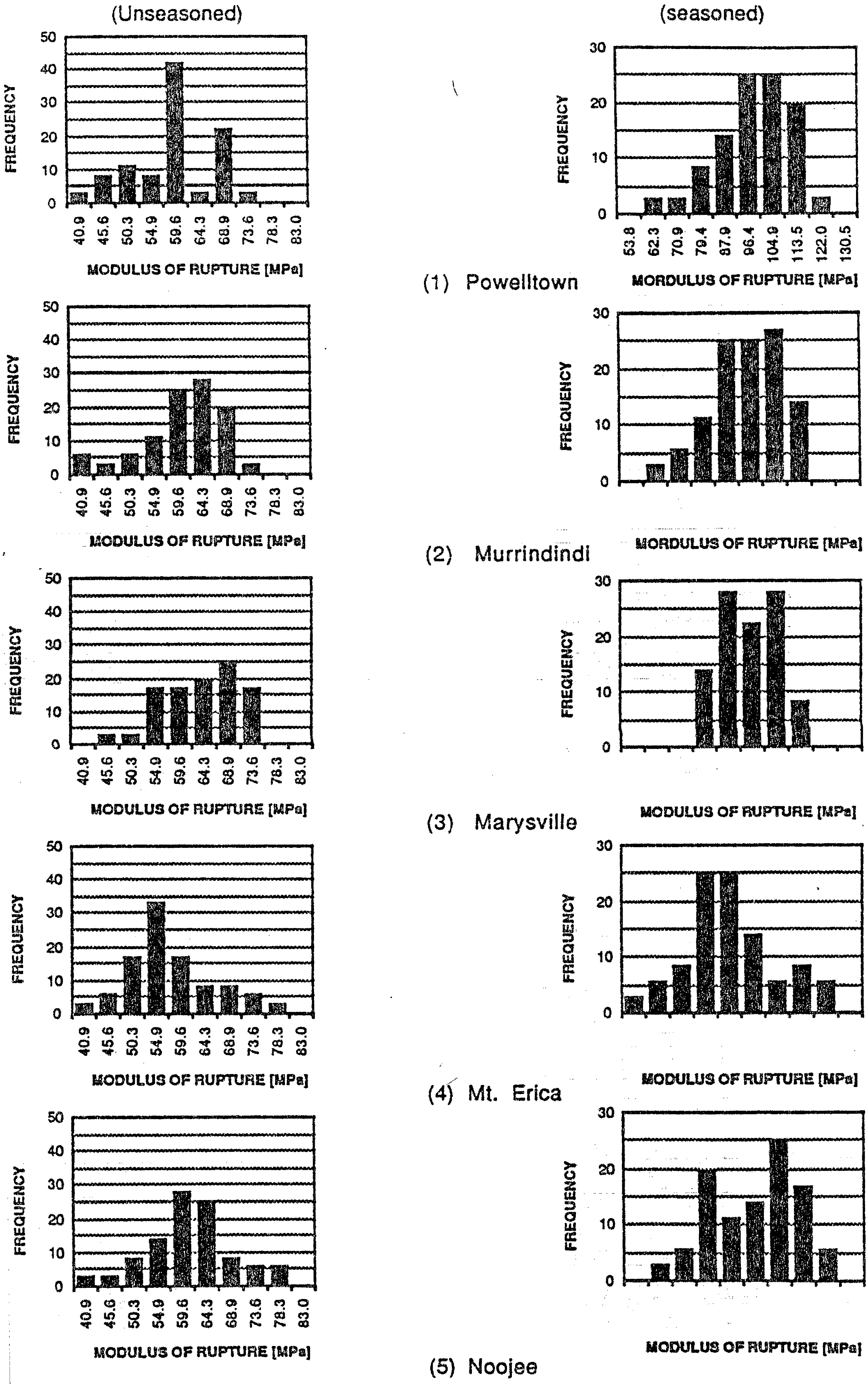


Figure 4.2. Histograms of modulus of elasticity of unseasoned and seasoned timber of 1939 regrowth E. regnans from Victoria.

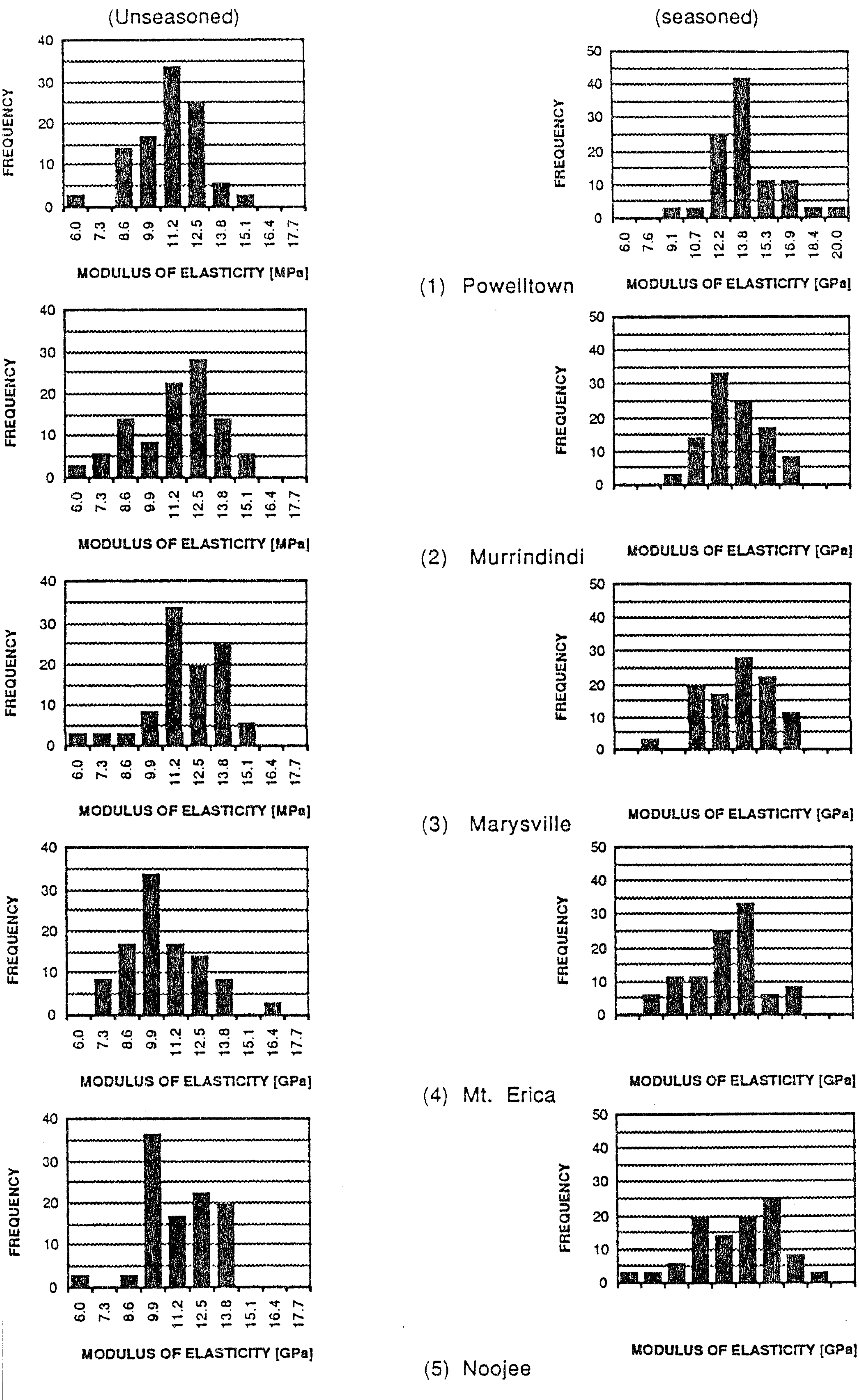


Figure 4.3. Histograms of maximum crushing strength of unseasoned and seasoned timber of 1939 regrowth E. regnans from Victoria.

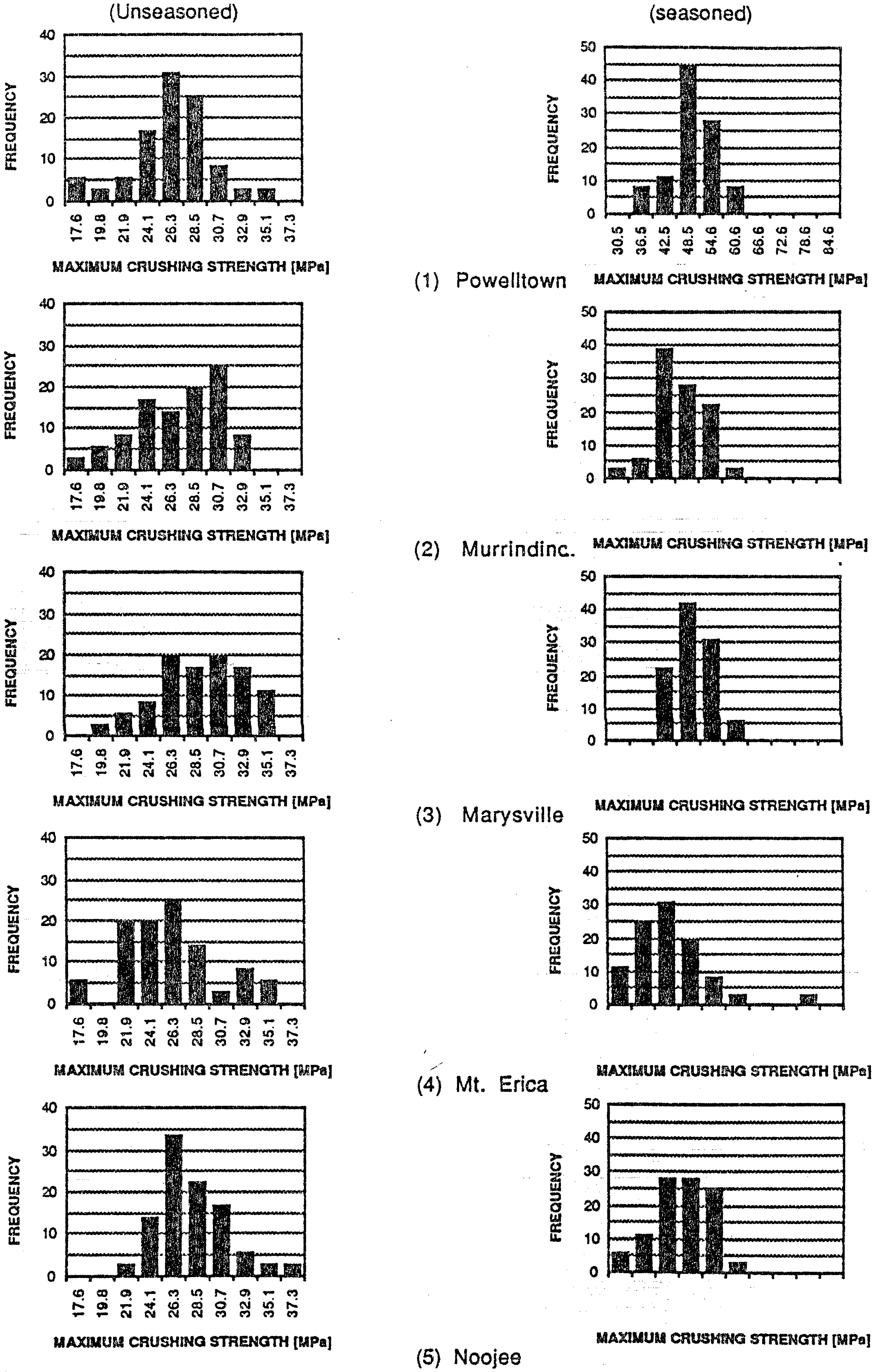
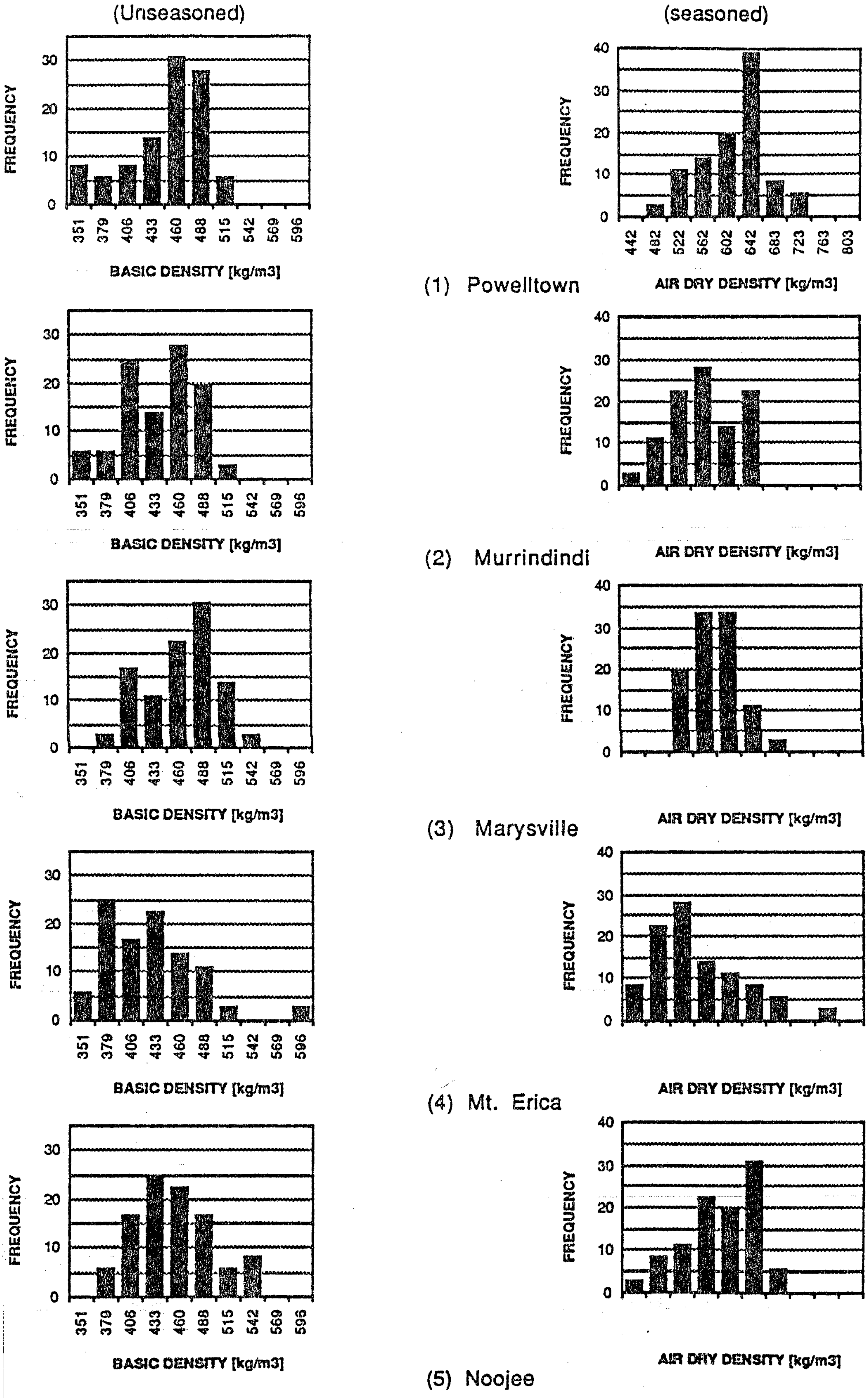


Figure 4.4. Histograms of basic and air dry density of timber of 1939 regrowth E. regnans from Victoria.



The inconsistencies in the deviation of the distributions from normal may either be an inherent characteristic of the strength properties themselves or be related to sample size. Further tests were undertaken to establish this.

The Scottsdale and Toolangi studies had indicated there was no strong relationship between strength properties and growth rate as measured by log diameters in even aged stands. The subsequent sampling of butt logs only was based on this result. Nevertheless, it was decided to check this result in relation to the five localities. The association between small end diameter of the butt logs and strength properties was examined using the "Spearman Correlation Test"(Tables 4.9 and 4.10).

Table 4.9 shows the test results for the association between small end diameter of logs and the strength properties of unseasoned timber suggesting that the strength properties of the unseasoned timber were not associated with small end diameter, except for timber from Mt. Erica where there is a significant association between small end diameter and both MOE and MCS and timber from Noojee where MCS was significantly associated with small end diameter of logs.

Table 4.9. Test statistics and related levels of significance obtained by "Spearman correlation" tests for the association between strength properties and small end diameter of butt logs for the unseasoned 1939 regrowth E. regnans.

Variable 1	Variable 2	Number of observations	Test Statistic	Level of Signific.
Powelltown				
MOR	SED	36	- 0.114	ns
MOE	SED	36	- 0.072	ns
MCS	SED	36	- 0.163	ns
BD	SED	36	- 0.327	ns
Murrindindi				
MOR	SED	36	0.328	ns
MOE	SED	36	0.237	ns
MCS	SED	36	0.266	ns
BD	SED	36	0.235	ns
Marysville				
MOR	SED	36	- 0.008	ns
MOE	SED	36	- 0.226	ns
MCS	SED	36	0.011	ns
BD	SED	36	- 0.129	ns
Mt. Erica				
MOR	SED	36	- 0.229	ns
MOE	SED	36	- 0.338	*
MCS	SED	36	- 0.399	*
BD	SED	36	- 0.204	ns
Noojee				
MOR	SED	36	- 0.278	ns
MOE	SED	36	- 0.217	ns
MCS	SED	36	- 0.383	*
BD	SED	36	- 0.191	ns

Table 4.10 shows the association between small end diameter of logs and strength properties of seasoned timber. There is no significant association between small end diameter and the properties of the seasoned timber from Powelltown, Murrindindi and Noojee. All the properties of seasoned timber from Mt. Erica are significantly associated with small end diameter as are air dry density and MCS of seasoned timber from Marysville.

Table 4.10. Test statistics and related levels of significance obtained by "Spearman correlation" tests for the association between strength properties and small end diameter of butt logs for the seasoned 1939 regrowth E. regnans.

Variable 1	Variable 2	Number of observations	Test Statistic	Level of Significance.
Powelltown				
MOR	SED	36	- 0.288	ns
MOE	SED	36	- 0.214	ns
MCS	SED	36	- 0.258	ns
ADD	SED	36	- 0.030	ns
Murrindindi				
MOR	SED	36	0.220	ns
MOE	SED	36	- 0.120	ns
MCS	SED	36	0.028	ns
ADD	SED	36	- 0.110	ns
Marysville				
MOR	SED	36	- 0.267	ns
MOE	SED	36	- 0.324	ns
MCS	SED	36	- 0.389	*
ADD	SED	36	- 0.371	*
Mt. Erica				
MOR	SED	36	- 0.439	* *
MOE	SED	36	- 0.607	* *
MCS	SED	36	- 0.633	* *
ADD	SED	36	- 0.450	* *
Noojee				
MOR	SED	36	- 0.322	ns
MOE	SED	36	- 0.154	ns
MCS	SED	36	- 0.236	ns
ADD	SED	36	- 0.161	ns

The relationship between small end diameter and MOR was also investigated by linear regression. The results are presented in Appendix 9. These show no strong relationships with correlation coefficients ranging over the five locations from 0.06 to 0.48 for seasoned timber and from 0.10 to 0.44 for unseasoned timber.

Relationships between strength properties plus density were also investigated by linear regression (Figures 4.5 to 4.12).

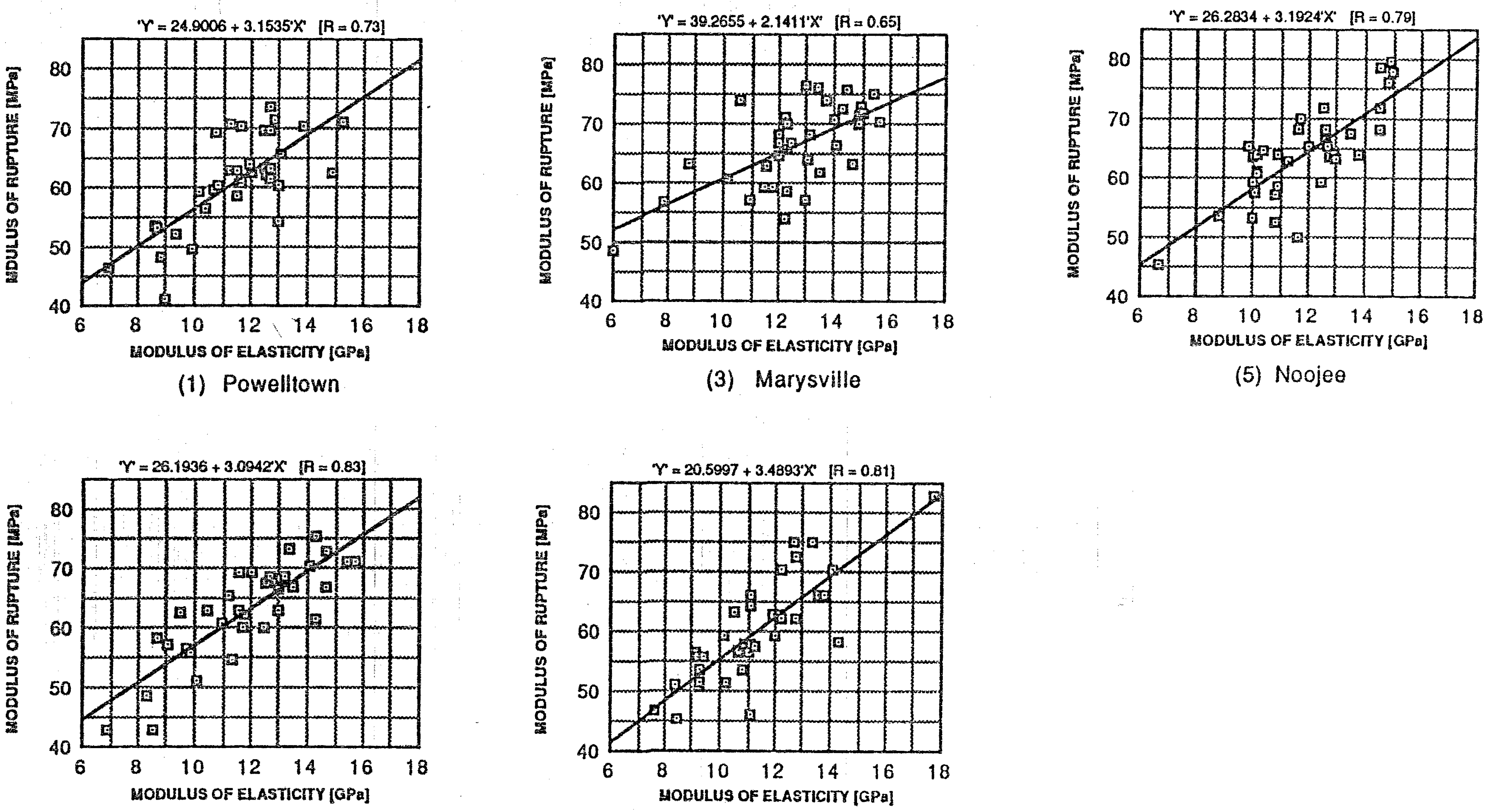
Figures 4.5 and 4.6 show the relationship between MOR and MOE for unseasoned and seasoned timber respectively. Both Figures suggest significant relationships between MOR and MOE for 1939 regrowth E. regnans. However, the correlation coefficients vary from 0.65 (Marysville) to 0.83 (Murrindindi) for unseasoned timber and from 0.71 (Murrindindi) to 0.92 (Noojee).

Figures 4.7 and 4.8 show the relationship between MOE and MCS for unseasoned and seasoned timber respectively. These show inconsistencies for both unseasoned and seasoned timber. The correlation coefficients range from 0.11 to 0.88 for unseasoned timber and from 0.12 to 0.67 for seasoned timber.

Figures 4.9 and 4.10 show the relationships between MOR and MCS for unseasoned and seasoned timber respectively. These show inconsistency for unseasoned timber in that the relationship is strong for Murrindindi but not for the others, whilst for seasoned timber the relationship is strong for Powelltown, Marysville and Mt. Erica but not for Murrindindi and Noojee. Correlation coefficients range from 0.26 (Powelltown) to 0.89 (Murrindindi) and from 0.06 (Murrindindi) to 0.65 (Marysville) for unseasoned and seasoned timber respectively.

Figures 4.11 and 4.12 show strong relationships between basic density and MOR for unseasoned timber and between air dry density and MOR for seasoned timber, except for that between basic density and MOR for unseasoned timber from Powelltown (R = 0.58). The other values for 'R' range from 0.78 to 0.94.

Figure 4.5. Relationships between MOE and MOR for unseasoned timber of 1939 regrowth mountain ash from 5 localities in Victoria.



(1) Powelltown

(3) Marysville

(5) Noojee

(2) Murrindindi

) Mt. Erica

Figure 4.6. Relationships between MOE and MOR for seasoned timber of 1939 regrowth mountain ash from 5 localities in Victoria.

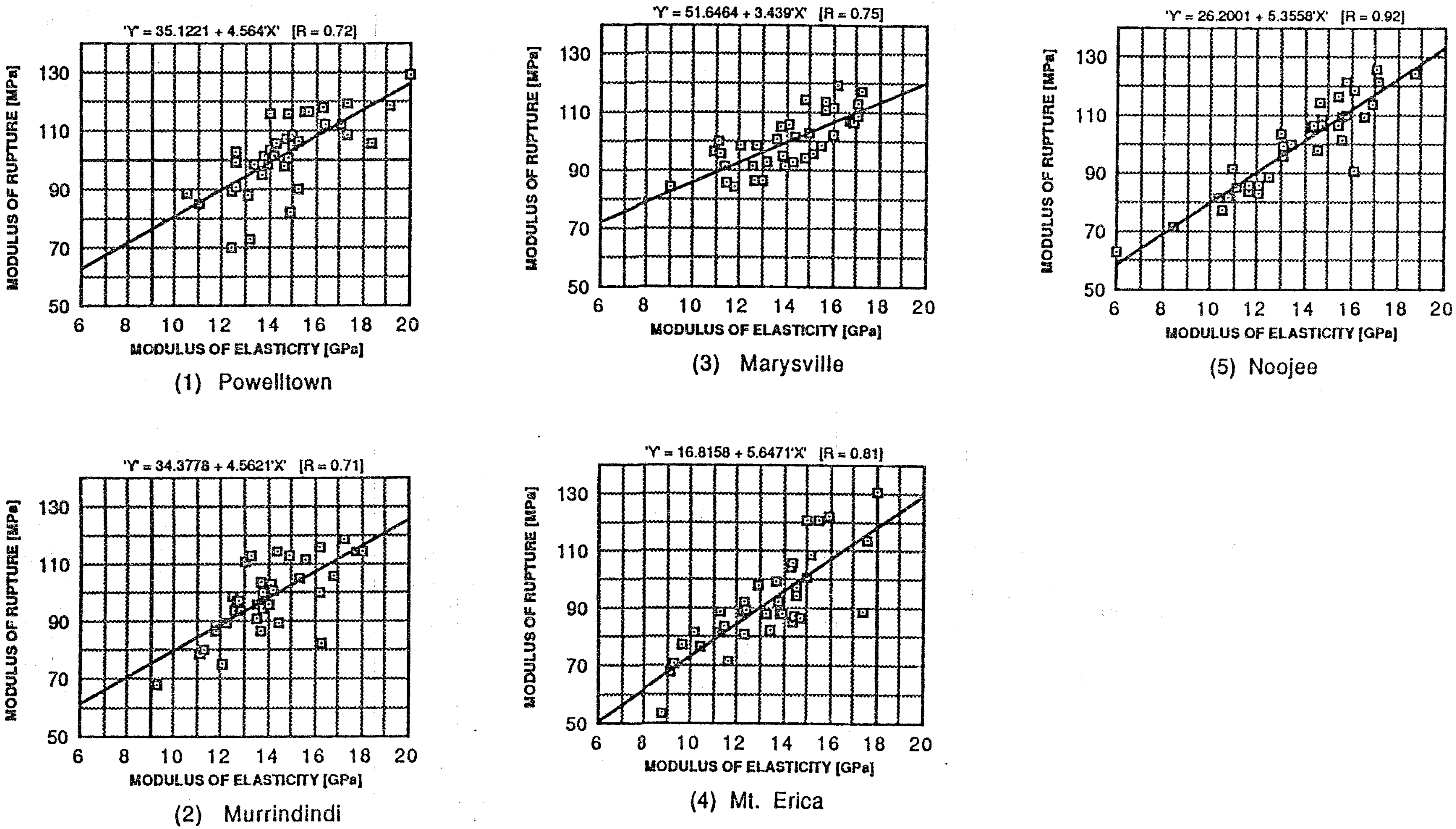


Figure 4.7. Relationships between MOE and MCS for unseasoned timber of 1939 regrowth mountain ash from 5 localities in Victoria.

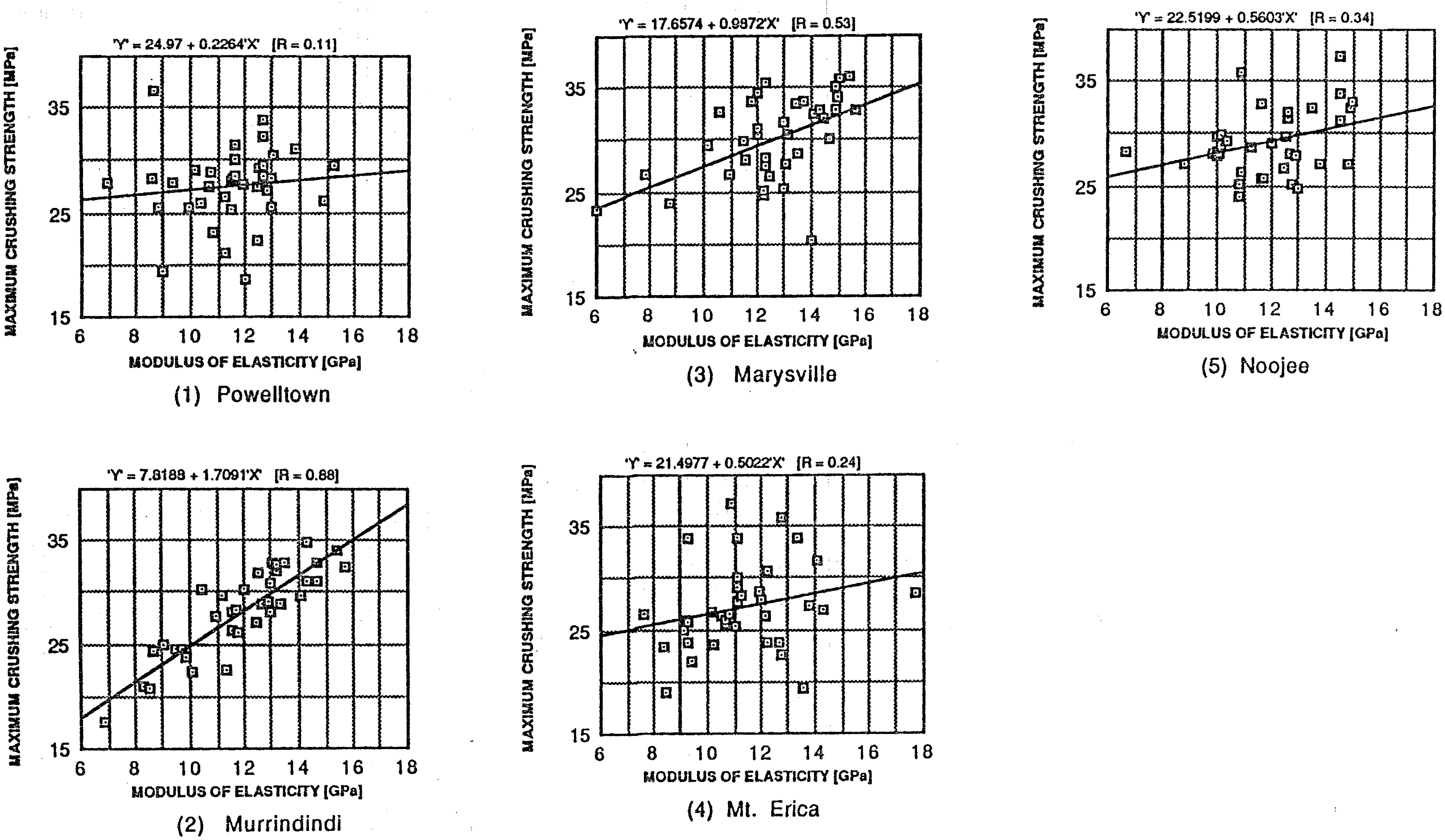
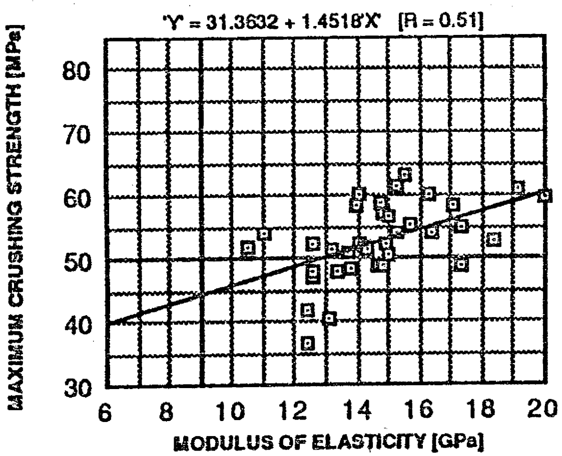
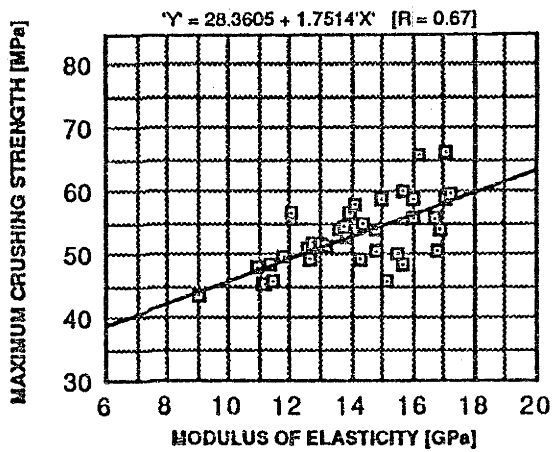


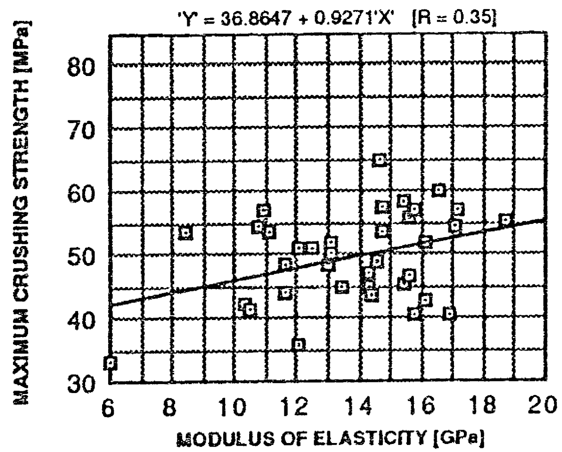
Figure 4.8. Relationships between MOE and MCS for seasoned timber of 1939 regrowth mountain ash from 5 localities in Victoria.



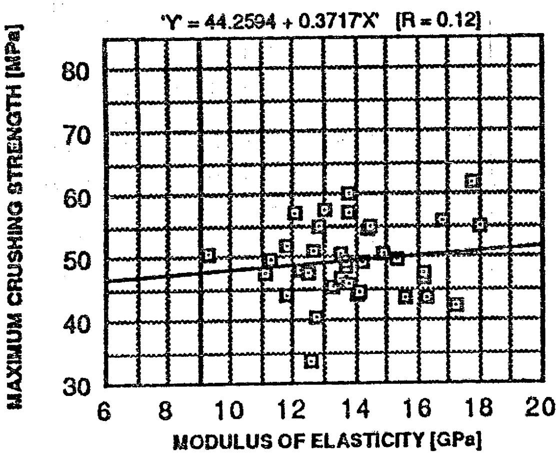
(1) Powelltown



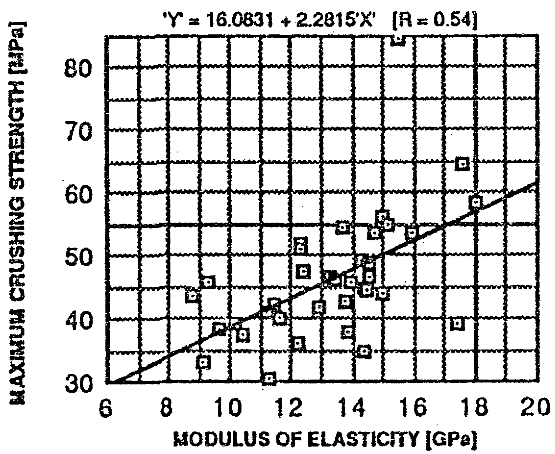
(3) Marysville



(5) Noojee



(2) Murrindindi



(4) Mt Erica

Figure 4.9. Relationships between MOR and MCS for unseasoned timber of 1939 regrowth mountain ash from 5 localities in Victoria.

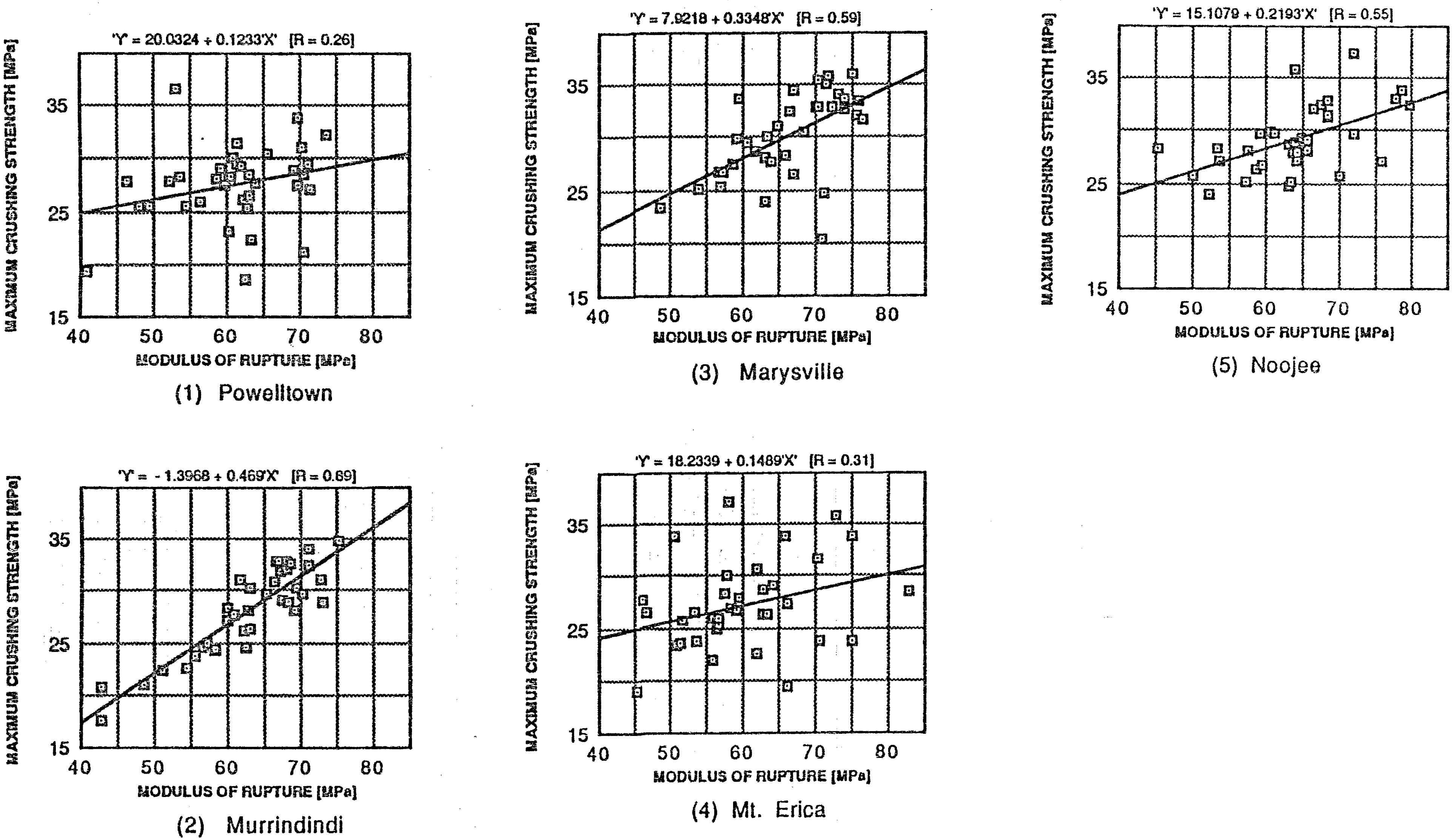


Figure 4.10. Relationships between MOR and MCS for seasoned timber of 1939 regrowth mountain ash from 5 localities in Victoria.

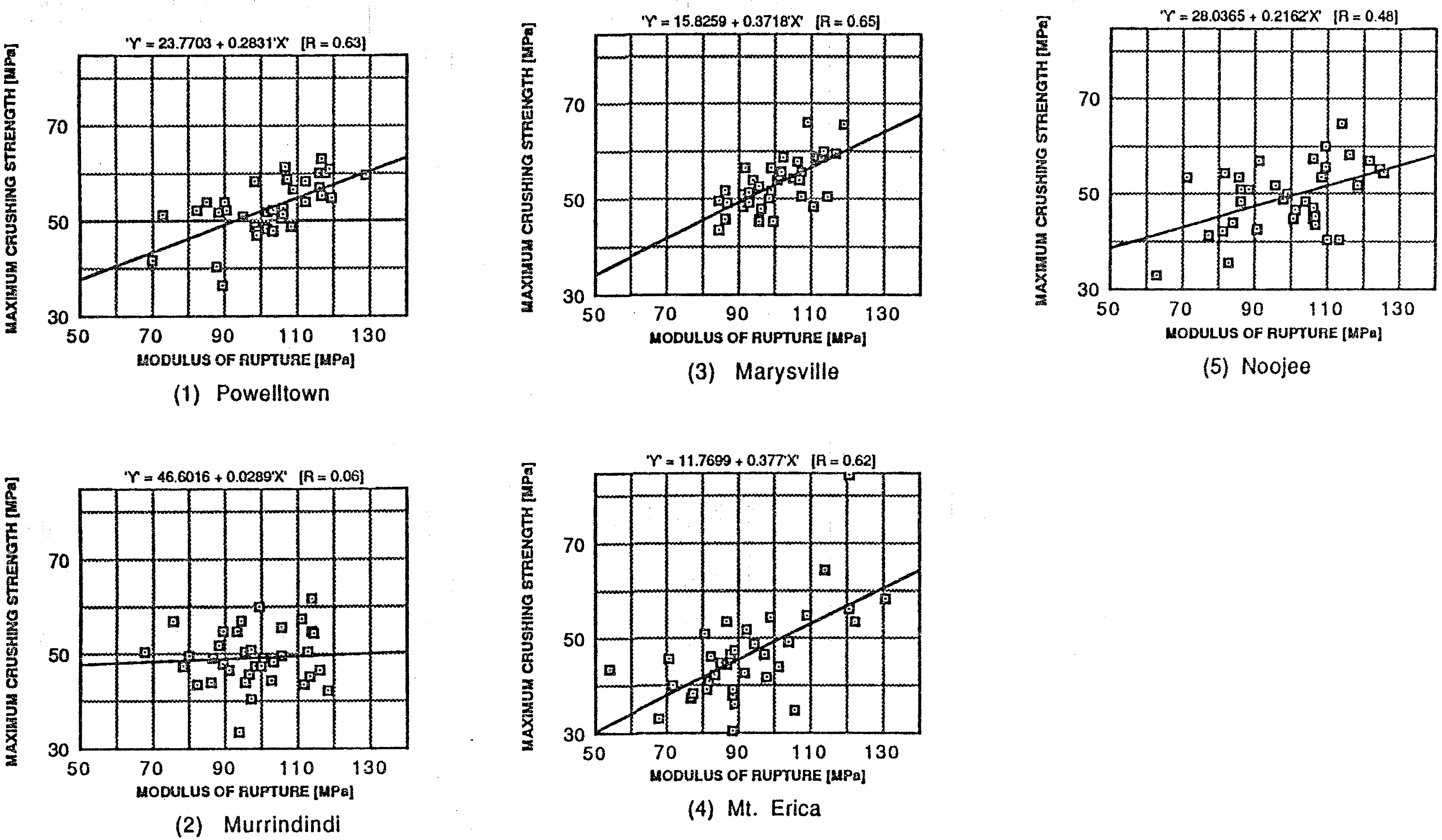


Figure 4.11. Relationships between Basic Density and MOR for unseasoned timber of 1939 regrowth mountain ash from 5 localities in Victoria.

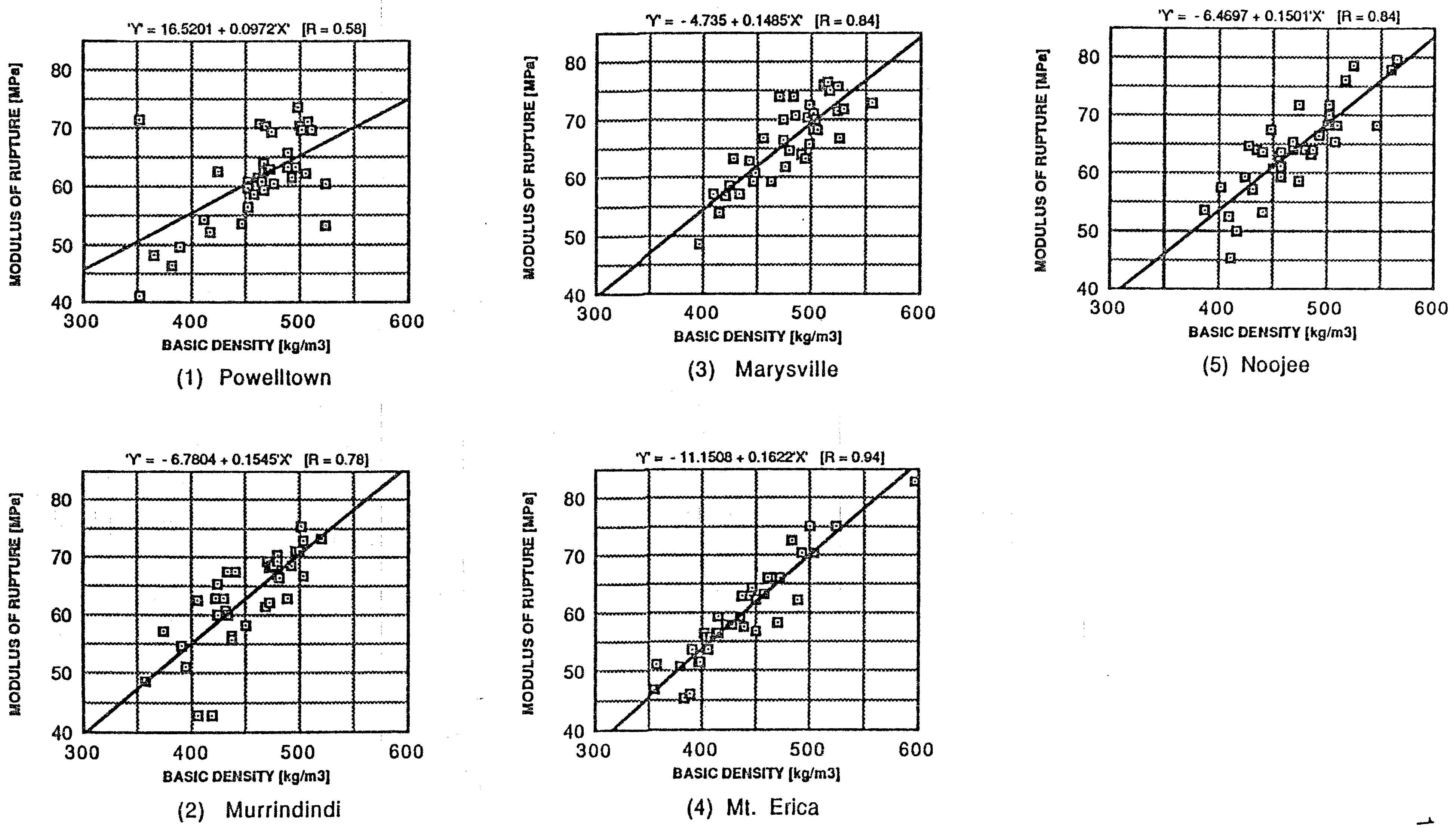
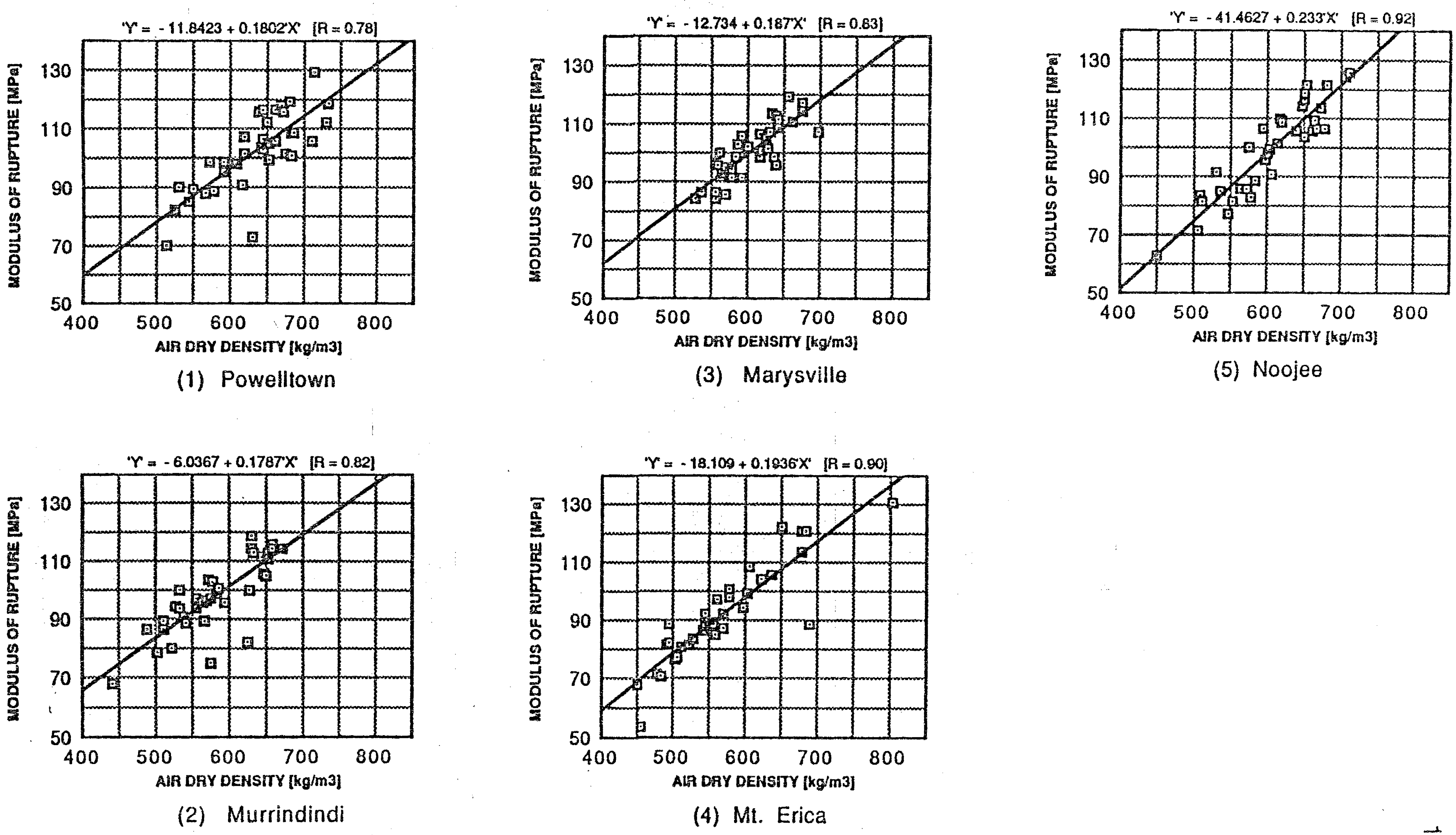


Figure 4.12. Relationships between Air Dry Density and MOR for seasoned timber of 1939 regrowth mountain ash from 5 localities in Victoria.



4.3.2. APPLICATION OF DATA FOR STRENGTH GROUPING

Positive strength grouping was used to strength group the material by locality. The results are presented in Table 4.11.

Table 4.11. Positive strength grouping of timber from even-aged stands of 1939 regrowth E. regnans from 5 localities in Victoria

Locality	Property	Unseasoned Mean value	Unseasoned Strength group	Seasoned Mean value	Seasoned Strength group
Powelltown	MOR [MPa]	61.2	S5	102.2	SD4
	MOE [GPa]	11.5	S4	14.7	SD4
	MCS [MPa]	27.6	S5	52.7	SD5
	Overall strength group		S5		SD4
Murrindindi	MOR [MPa]	63.0	S4	97.8	SD4
	MOE [GPa]	11.9	S4	13.9	SD5
	MCS [MPa]	28.2	S5	49.4	SD5
	Overall strength group		S4		SD5
Marysville	MOR [MPa]	66.3	S4	100.1	SD4
	MOE [GPa]	12.6	S3	14.1	SD4
	MCS [MPa]	30.1	S5	53.1	SD5
	Overall strength group		S4		SD4
Mt. Erica	MOR [MPa]	60.0	S5	91.8	SD5
	MOE [GPa]	11.3	S4	13.3	SD5
	MCS [MPa]	27.2	S5	46.4	SD6
	Overall strength group		S5		SD5
Noojee	MOR [MPa]	63.9	S4	99.7	SD4
	MOE [GPa]	11.8	S4	13.7	SD5
	MCS [MPa]	29.1	S5	49.6	SD5
	Overall strength group		S4		SD5
Mature ash	Overall strength group		S4		SD3

There are variations in the preliminary strength groups for each property at all localities. However, these have been dealt with according to AS 2878 which provides for certain combinations of preliminary classifications to permit the overall strength group assessment to be one step above the lowest in the combination if this applies to one value only. Otherwise the minimum preliminary strength group was adopted as the overall strength group.

The overall strength groups for unseasoned and seasoned timber from Mt. Erica of S5, SD5 and for unseasoned timber from Powelltown of S5 are in agreement with the strength groups proposed by Breitinger (1987).

However there are variations between the overall strength groups in that unseasoned timber from Powelltown and Mt. Erica are grouped as S5, the other as S4; whilst seasoned timber from Murrindindi, Mt. Erica and Noojee are grouped as SD5, the others as SD4. The minimum strength groups for unseasoned and seasoned timber are thus S5 and SD5 respectively.

The variations in strength groups are not related to the elevation of the area from which the timber came. The strength group of unseasoned timber from the highest elevation (Mt. Erica) is equal to that from the lowest elevation (Powelltown), whilst the strength group of seasoned timber from the highest elevation (Mt. Erica) is one step lower than that from the lowest elevation (Powelltown). Elevation would not be an appropriate criterian to assist in classifying the 1939 regrowth E. regnans into strength groups.

Table 4.11 also shows that mature E. regnans has a generally higher strength group than the 1939 regrowth. In seasoned timber it is higher than any of the 5 localities; in unseasoned timber it is higher than Powelltown and Mt. Erica regrowth.

CHAPTER 5. SYNTHESIS OF THE STRENGTH GROUP FOR THE EVEN AGED STANDS OF 1939 REGROWTH E. REGNANS

5.1. INTRODUCTION

In the initial study (Chapter 3) the strength group of seasoned timber from an even-aged stand of 1939 regrowth at Toolangi, Victoria was shown to differ from that for mature E. regnans. In a subsequent study (Chapter 4) the strength group of both unseasoned and seasoned timber from even-aged stands of 1939 regrowth E. regnans from Powelltown, Murrindindi, Marysville, Mt. Erica and Noojee were generally shown to differ from mature wood.

However, within the regrowth wood tested there was variation in strength group according to locality. It, therefore, seems necessary to review the strength group for the single species E. regnans and it may be desirable, in practice, to adopt different strength groups for the mature and regrowth wood of this species.

In this Chapter the question of an appropriate strength group or groups for 1939 regrowth E. regnans timber is examined further.

Separate strength groups for individual localities would pose difficulties in marketing and utilization of regrowth timber because some localities are close to each other and timber from two localities could be produced at one sawmill e.g sawlogs from Mt. Erica and Noojee are milled at Drouin West. Nonetheless, such problems could be resolved, for example by careful branding of logs by locality to enable subsequent branding of individual pieces of sawn timber.

On the other hand, some timber would be down-graded if one strength group only was adopted for the 1939 regrowth.

To determine an appropriate strength group for the 1939 regrowth E.

regnans from Victoria, the results were synthesized to obtain a representative population of test specimens of unseasoned and seasoned timber.

5.2. METHODOLOGY

Rather than combine the test results from each of six localities the respective random normal deviates[1] were generated using the mean and standard deviation of each property for each locality to avoid the unusual data points included in the samples. These were then used as a synthetic set of results for each property, related to locality. The number of observations for the value of each property could then be increased as required.

A number of sets of 1000 random normal deviates were generated for each of the 6 localities that is Powelltown, Murrindindi, Marysville, Mt. Erica, Noojee and Toolangi. Each locality was given equal weight because data were insufficient to weight according to volume of production.

Strength grouping using synthesized data was done twice as a check.

---

1 See appendix 10.

5.3. RESULTS AND DISCUSSION

The mean values of the synthesized data were used to strength group the total regrowth population. The strength groups derived from two trials are presented in Table 5.1.

Table 5.1. Positive strength grouping from a synthesized resource of 1939 regrowth E. regnans.

(a) Trial 1

Property	Unseasoned		Seasoned	
	Mean value	Strength group	Mean value	Strength group
MOR [MPa]	63.2	S4	98.5	SD4
MOE [GPa]	11.8	S4	14.0	SD4
MCS [MPa]	29.0	S5	50.0	SD5
Overall strength group		S4		SD4

(b) Trial 2

Property	Unseasoned		Seasoned	
	Mean value	Strength group	Mean value	Strength group
MOR [MPa]	63.1	S4	98.6	SD4
MOE [GPa]	11.8	S4	14.0	SD4
MCS [MPa]	29.0	S5	50.3	SD5
Overall strength group		S4		SD4

In both trials, the overall strength group was S4 for unseasoned timber, SD4 for seasoned: effectively up-grading the regrowth by one strength group compared with the results reported in Chapter 4.

The practical consequences of such upgrading would have to be investigated since, for example the material for one house could all come from one sawmill producing timber at a lower grade than S4, SD4.

CHAPTER 6. BASIC WORKING STRESSES FOR REGROWTH E. REGNANS

6.1. INTRODUCTION

The basic working stress for clear timber in bending is derived from the species mean value for MOR but includes allowances for the inherent variability of wood, duration of loading, accidental over load and other incalculables (Appendix 2). The allowance for inherent variability has been determined from the average inherent variability of 174 Australian species that is average standard deviation or coefficient of variation (Bolza and Kloot, 1963). Therefore, for a species with an inherent variability greater than the average value allowed in the establishment of strength group limits, the calculated basic working stress in bending of structural grade no.1, derived from actual test data and species variability, may be less than the prescribed basic working stress based on an average value. For example, when the species mean value for MOR falls just above the strength group limit and the overall strength group is the same as the preliminary strength group for MOR but test results for MOR are very variable, then the 1% lower probability limit based on the mean value of the test results assuming normal distribution may be less than that based on the lower limit of the strength group. .

However, three strength properties, including MOR are used as parameters in strength grouping and the overall strength group of a species is determined by a combination of three preliminary groups (Chapter 2). As a result, the overall strength group of a species may, for individual strength properties, give values greater than, equal to or less than the values for the preliminary strength groups. For seasoned timber from Murrindindi and Marysville, for example, the overall strength group at each locality is SD5 while the preliminary strength group for MOR is SD4 (Chapter 4). Thus the basic working stress in bending of structural grade no.1 calculated from test results would be greater than that based on strength grouping

In general, when the overall strength group is one step lower than the preliminary strength group for MOR, structural design would be conservative in respect of bending.

The overall strength group of the species and the preliminary strength group for MOR are the same for unseasoned timber from the 1939 regrowth stands at Murrindindi and Marysville, and for unseasoned and seasoned timber from the 1927 regrowth stands at Scottsdale, Tasmania and from the 1939 regrowth stands at Toolangi, Powelltown, Mt. Erica and Noojee. However, since the test results reported have greater variability than was assumed by Pearson (1966) in deriving strength groups, the calculated stress in bending of structural grade no.1 for these timbers may be lower than the prescribed stress and structural design would not be conservative.

Comparisons of prescribed and calculated basic working stresses enable the effect of upgrading to be assessed (as would occur if the 'synthetic' strength groups derived in Chapter 5 were adopted). If these synthetic strength groups were accepted, unseasoned timber from Powelltown and Mt. Erica and seasoned timber from Murrindindi, Mt. Erica and Noojee would be upgraded. In a practical sense it is important to assess the consequences of such upgrading since material for one house could all come from one sawmill providing timber at a lower grade than that derived from the synthetic strength groups S4 and SD4.

Two comparisons will be made to assist in assessing the practical consequences of upgrading; firstly between the prescribed basic working stress for structural grade no.1 based on the strength group for each locality and the corresponding calculated values and secondly, between the prescribed basic working stress for structural grade no.1 of the 'synthetic' strength group and the corresponding calculated values for each of the six localities of 1939 regrowth.

6.2. METHODOLOGY

The basic working stresses for MOR in timber of structural grade no.1 from 1927 regrowth E. regnans from Scottsdale, Tasmania and from 1939 regrowth E. regnans from the six localities in Victoria were calculated from the test results using first principles after Pearson (1965).

The basic working stresses in MOR for clear timber were calculated from the test results using the respective mean values for MOR and the standard deviations obtained by fitting both normal and log normal distributions. The inherent variability of wood was allowed for as discussed previously in this Chapter (see also Appendix 2). The calculated basic working stress for clear timber was then multiplied by 0.75 to obtain the stress in bending for structural grade no.1. Comparisons were then made between the calculated basic working stresses and those based on both the strength groups for individual localities and the synthetic strength groups for 1939 regrowth as a whole.

6.3. RESULTS AND DISCUSSION

Basic working stresses in bending prescribed for structural grade no.1 (unseasoned timber) based on the positive strength group values and the calculated values under normal and log normal distributions are shown in Table 6.1.

Table 6.1. Comparison between prescribed and calculated values of basic working stress in bending for structural grade no.1, unseasoned timber.

Locality	Positive[1)] strength group	Basic working stress in bending[2)] [MPa]		
		Prescribed[3)]	Calculated[4)]	
			Normal	Log normal
Scottsdale	S5	11.0	11.6	12.5
Powelltown	S5	11.0	14.6	15.0
Murrindindi	S4	14.0	15.0	15.3
Marysville	S4	14.0	17.0	17.3
Mt. Erica	S5	11.0	13.4	14.4
Noojee	S4	14.0	15.5	16.1
Toolangi	S4	14.0	14.3	15.5

1) Based on test results
2) Structural grade no.1
3) Australian Standard AS 1720, 1975
4) Based on normal and log normal distributions fitted to the test data.

Table 6.1 shows the basic working stresses in bending for structural grade no.1, unseasoned timber, calculated from both normal and log normal distributions are greater than the prescribed values for all localities. Thus the positive strength group of unseasoned timber from all localities is conservative in terms of bending irrespective of the variability and of whether or not the preliminary strength group (MOR) is lower than the overall strength group.

The same comparisons for seasoned timber are shown in Table 6.2.

Table 6.2. Comparison between prescribed and calculated values under normal and log normal distributions of basic working stress in bending for structural grade no.1 seasoned timber.

Locality	Positive[1)] strength group	Basic working stress in bending[2)] [MPa]		
		Prescribed[3)]	Calculated[4)]	
			Normal	Log normal
Scottsdale	SD5	17.0	15.1	17.2
Powelltown	SD4	22.0	24.0	24.8
Murrindindi	SD5	17.0	23.2	24.0
Marysville	SD4	22.0	26.3	26.9
Mt. Erica	SD5	17.0	18.1	20.0
Noojee	SD5	17.0	21.3	22.7
Toolangi	SD4	22.0	20.1	22.1

1) Based on test results
2) Structural grade no.1
3) Australian Standard AS 1720, 1975
4) Based on normal and log normal distributions fitted to the test data

Table 6.2 shows that the calculated basic working stresses in bending obtained by assuming a normal distribution for seasoned structural grade no.1 from Scottsdale and Toolangi are lower than the prescribed values. However, the values obtained from these two localities by assuming a log normal distribution are very slightly higher. The calculated basic working stresses for all other localities are higher than the prescribed values. Thus the positive strength groups are appropriate, that is the increased variability as compared to that assumed by Pearson (1966) does not take the calculated basic working stresses below the prescribed values.

Basic working stresses in bending prescribed for structural grade no.1, unseasoned timber, based on the synthetic strength group for all the 1939 regrowth E. regnans and the values calculated assuming both normal and log normal distributions are shown in table 6.3.

Table 6.3. Comparison between prescribed values of basic working stress in bending for the synthetic strength group and calculated values for structural grade no.1, unseasoned timber of 1939 regrowth.

Locality	Synthetic[1] strength group	Basic working stress in bending[2] [MPa]		
		Prescribed[3]	Calculated[4]	
			Normal	Log normal
Powelltown	S4	14.0	14.6	15.0
Murrindindi	S4	14.0	15.0	15.3
Marysville	S4	14.0	17.0	17.3
Mt. Erica	S4	14.0	13.4	14.4
Noojee	S4	14.0	15.5	16.1
Toolangi	S4	14.0	14.3	15.5

1) See Chapter 5 for derivation of synthetic strength group
2) Structural grade no.1
3) Australian Standard AS 1720, 1975 as applied to the synthetic strength group
4) Based on normal and log normal distributions fitted to the test data.

The calculated basic working stress in bending for structural grade no.1 timber from Mt. Erica assuming a normal distribution is 4% lower than the prescribed stress but that from the log normal distribution is 3% higher. For all other localities, the calculated basic working stresses assuming both normal and log normal distributions are higher than the prescribed stresses. Thus the prescribed stress would seem to be appropriate for all localities and the synthetic strength group for unseasoned timber applicable to these timbers for bending stress.

The same comparisons for seasoned timber are shown in Table 6.4.

Table 6.4. Comparison between prescribed values of basic working stress in bending for the synthetic group and the calculated values for structural grade no.1 for seasoned timber for 1939 regrowth.

Locality	Synthetic[1)] strength group	Basic working stress in bending[2)] [MPa]		
		Prescribed[3)]	Calculated[4)]	
			Normal	Log normal
Powelltown	SD4	22.0	24.0	24.8
Murrindindi	SD4	22.0	23.2	24.0
Marysville	SD4	22.0	26.3	26.9
Mt. Erica	SD4	22.0	18.1	20.0
Noojee	SD4	22.0	21.3	22.7
Toolangi	SD4	22.0	20.1	22.1

1) See Chapter 5.
2) for structural grade no.1
3) Australian Standard AS 1720, 1975
4) Based on normal and log normal distributions fitted to the test data.

The calculated basic working stresses in bending for structural grade no.1 of seasoned timber assuming both normal and log normal distributions for Powelltown, Murrindindi and Marysville are higher than the prescribed stress. The calculated basic working stresses assuming a log normal distribution for Noojee and Toolangi are also higher but those assuming a normal distribution are lower. For Mt. Erica, the calculated basic working stresses for both distributions for Mt. Erica are lower than the prescribed stress, 18% and 9% respectively. Except for Mt. Erica, therefore, the basic working stresses in bending for structural grade no.1 in seasoned timber are generally compatible with the prescribed stress based on the synthetic strength group.

In terms of convenience, there would be considerable advantage if the one strength group SD4 could be applied to seasoned regrowth E. regnans. However, the Mt. Erica timber does not meet the requirements for SD4 and there may be other sources of regrowth E. regnans having similar properties. The safest approach would, therefore, entail adopting the SD5 group overall.

CHAPTER 7. REVIEW AND CONCLUSIONS

7.1. INTRODUCTION

Safety and efficient use of the material are prime concerns when using timber structurally. Strength grouping is a system for combining the very large number of wood species into a small number of strength groups such that all the species in a group have strength properties within a defined range and, for structural design purposes, one set of engineering design stresses.

The strength grouping system developed in Australia is based on values of MOR, MOE and MCS as measured by tests of small clear specimens obtained from an appropriate number of wood samples. Each species will fall into only two strength groups; one for unseasoned, one for seasoned timber.

In Australia, regrowth eucalypt forests are becoming a major hardwood resource and an important source of structural timber. In Victoria in particular, the even aged stands of regrowth E. regnans regenerated after the 1939 bush fire are now being logged. However, there is concern that the strength properties of the regrowth timber are substantially lower than those used in structural design for timber from mature trees.

This study was designed to assist in strength grouping of regrowth E. regnans. It was undertaken in association with the 'Young Eucalypt Program'.

7.2. MATERIAL TESTED

All the material was of one species, E. regnans (mountain ash).

1. 1927 regrowth from Scottsdale, Tasmania.
2. 1939 regrowth from Toolangi, Victoria.
3. 1939 regrowth from Powelltown, Murrindindi, Marysville, Mt. Erica and Noojee, Victoria.

7.3. RESULTS

Table 7.1. Strength groups of timber from the even aged 1939 regrowth E. regnans in Victoria.

Timber	Unseasoned	Seasoned
1927 regrowth		
Scottsdale	S5	SD5
1939 regrowth		
Powelltown	S5	SD4
Murrindindi	S4	SD5
Marysville	S4	SD4
Mt. Erica	S5	SD5
Noojee	S4	SD5
Toolangi	S4	SD4
Mature	S4	SD3

Table 7.1 suggests that regrowth and mature E. regnans should be distinguished for strength grouping purposes.

No evidence was found that age strongly affected the strength properties of the regrowth tested. Therefore, further work is necessary to define at what age E. regnans becomes mature for strength grouping purposes and if there is a lower limit to the age of regrowth E. regnans at which the strength groups found in this study would not be appropriate. A carefully designed experiment to sample a wide range of age classes of E. regnans would be required to enable conclusive assessment of the effect of age.

There was no evidence that growth rate influenced strongly the strength properties of the wood. At all sites, statistical tests for linear relationships between strength properties and log diameter (used as an indicator for growth rate in even aged stands) gave a poor correlation coefficient. It was concluded log diameter in an even aged stand would not be a practical predictor for discriminatory strength groups.

There was no evidence that topographic elevation of the stands within the 1939 regrowth in Victoria influenced, in a consistent way the strength properties of the timber. This factor, also, would not be a practical predictor for discriminatory strength groups.

While there were differences in strength groups between the sites sampled there would be practical difficulties in strength grouping by site within the 1939 regrowth. For example some of the localities sampled were in close proximity; timber from more than one sites could be milled at one sawmill and discrimination between sites would require segregation of sawn timber and separate branding.

The results of a 'synthetic' strength grouping system discussed in Chapter 5 could be applied to the 1939 regrowth in Victoria. Based on analyses of the tests reported in this thesis appropriate strength groups could be S4 for unseasoned and SD4 for seasoned timber except for timber from Mt. Erica for which now appropriate strength groups would be S5 and SD5. If these synthetic strength groups were accepted, branding would be required to discriminate between Mt. Erica and other timbers.

Comparisons were made of basic working stresses in bending assuming both normal and log normal distributions. The test results are well fitted to the log normal distribution and it provides less conservative basic working stresses than if a normal distribution is assumed.

7.4. REVIEW OF THE RESULTS

Since the strength properties of the regrowth timbers tested are inferior to those of wood from mature trees, it is necessary to define them as a 'new species' for structural use. The strength groups recommanded for consideration by the approving authorities, and based on a synthesis of the data presented would be S4 and SD4 for unseasoned and seasoned timber respectively. However, special consideration would be required for 'Mt. Erica' timber. An alternative and more conservative approach would be to adopt the minimum strength groups for unseasoned and seasoned timber found in the seven localities sampled. On this basis the strength groups of regrowth E. regnans would be S5 and SD5 for unseasoned and seasoned timber respectively.

7.5. FUTURE RESEARCH

Although the strength grouping system is based on the strength properties of defect free timber, its use for the design of structures must take defects into account. Thus the mechanical testing reported in this study should be related to results from 'in grade' testing and the effects of defect on strength properties.

Since the strength group or groups of regrowth E. regnans are different from accepted values for mature ash and, furthermore, that even within the regrowth material there are differences in strength groups by locality and at this stage uncertainty with respect to the effect of age and silvicultural treatment on strength properties, it is desirable a mechanical stress grading system be developed and tested. However, the results of this study indicate this will not be straightforward: even for defect free seasoned timber the correlation coefficient between MOE and MOR varies between the seven localities from which wood was obtained.

The uncertainty of the effect of aging raising the question of when the strength properties of regrowth will approach those for mature wood could be investigated in two ways. Firstly the strength properties of wood from trees from even aged stands and a range of age or age classes could be investigated and the trend of strength properties with age identified. Secondly investigations could be made within single trees of wood according to cambial age. Thus variations in the strength properties laterally and longitudinally, could be investigated. Such analyses would help to resolve the uncertainty of the effect of aging.

The question of why regrowth of this eucalyptus species has lower values for MOR, MOE and MCS than wood from a mature source needs to be addressed further. The lower strength factors such as anatomical differences, higher growth stresses, difference in grain spirality or micro fibril angles.

APPENDIX 1

TERMS AND DEFINITIONS

Basic working stress

The stress appropriate to an arbitrarily chosen, but constant, basic reference set of conditions. It is derived from the known strength properties of a timber, due allowance having been made for such factors as material variability, long-duration loading, grade of timber, and a safety factor.

Coefficient of variation

The coefficient of variation of a set of 'n' measurements $y_1, y_2, y_3, \ldots, y_n$ is equal to the standard deviation (s) expressed as a percentage of the mean y.

$$C.V\ [\%] = \frac{s * 100}{y}$$

Confidence half-range

There is a high probability that the population mean is within a certain percentage interval of the sample mean. This more convenient measure of variability may be calculated from the interval between the sample mean and a limit within which values may fall with probability P. For most purposes, a probability of 95% is sufficient. This interval, expressed as a percentage of the mean, is termed the confidence half-range.

$$H = (100 * s/y) * t_{0.05}$$

where H = the 95% confidence half-range

s = the standard error of the species mean

y = the estimate of the species mean

and $t_{0.05}$ = the t-value at the 95% probability level for m-1 degrees of freedom, 3 when equal numbers of specimens are taken from each of m trees.

Lower probability limit

Under the normal distribution curve, the estimated limit below which not more than a particular percentage of the test results will be expected to fall is known as the lower probability limit. In relation to strength grouping a 1% lower probability limit is usually applied. This limit can be calculated for any strength property as follow.

1% Lower probability limit = (Mean value) - (2.33 x Standard deviation)

Maximum Crushing Strength

The ultimate strength attained under a load slowly applied parallel to the grain. A species mean value derived from test result indicates relative suitability of that species for use as a short column.

Mean (Arithmetic mean)

The mean of a set of 'n' measurements $y_1, y_2, y_3, \ldots, y_n$ is equal to the sum of the measurements divided by 'n'.

$$\text{Sample mean: } y = \frac{\Sigma y_i}{n}, \qquad i = 1,2,3, \ldots\ldots\ldots\ldots, n.$$

Modulus of Rupture

A measure of the ultimate short-term load-carrying capacity of a beam when the load is applied slowly.

Modulus of Elasticity

A measure of stiffness and resistance to deflection.

Population

A population is the set representing all measurements of interest to the sample

Sample

A sample is a subset of measurements selected from the population of interest.

Standard deviation

The standard deviation of a set of 'n' measurements $y_1, y_2, y_3, \ldots, y_n$ is equal to the positive square root of the variance.

$$s = \mathrm{sqrt}\left(\frac{\Sigma\,(yi - y)^2}{n-1}\right), \qquad i = 1,2,3, \ldots\ldots\ldots, n.$$

Stress grade

The classification of a piece of timber for structural purposes by means of species identification and either visual or mechanical grading to indicate primarily the basic working stress in bending for purposes of design and, by implication, the basic working stresses for other properties normally used in engineering design. The stress grade is designated in a form such as 'F7' which indicates that, for such a grade of material, the basic working stress in bending is approximately 7 MPa.

Strength group

The classification into which a timber species or species group, is assigned on the basis of the mechanical properties of defect free material or density determinations of the species.The positive strength group to which a timber species is assigned based on testing of small clear specimens from five or more trees to determine mechanical strength properties. Testing must be in accordance with the standard methods such as the methods proposed by Mack (1979). The provisional strength group to which a timber species is assigned on the basis of density or limited mechanical test data.

Variance of a sample

The variance of a sample of 'n' measurements $y_1, y_2, y_3, \ldots\ldots, y_n$ is defined as the sum of the squared deviations of the measurements about their mean (y) divided by (n-1). The sample variance is denoted by s^2 and is given by the formula

$$s^2 = \frac{\Sigma\ (y_i - y)^2}{n-1}, \qquad i = 1,2,3, \ldots\ldots\ldots\ldots, n.$$

Appendix 2

DERIVATION OF BASIC WORKING STRESSES

The stress appropriate to an arbitrarily chosen but constant, reference set of conditions is termed the basic working stress (AS-1720, 1975). It is equivalent to the maximum allowable stress under dead load derived from the extreme fibre stress obtained by testing small clear specimens. The variation in the strength properties of small clear specimens, the effect of duration of load, accidental overloads and other incalculables and the reduction in strength due to the variation in size of the timber are taken into account in the derivation of basic working stress or maximum allowable stress under dead load (Pearson, 1965).

The mechanical testing of small clear specimens shows the variability in strength properties even within a single species. This variation is due to the inherent variability of timber and to sampling methods (Pearson, 1952). "When the results are plotted on a strength-frequency scale a curve is obtained which approximates the 'normal' distribution curve of statistics, the properties of which are well known. The variability of a particular strength property of a species can conveniently be measured by the standard deviation, or the coefficient of variation" (Comben, 1971). The properties of 'normal' distribution curve are used in the derivation to estimate the 1% lower probability value below which not more than a result of the test out of hundred will be expected to fall. For bending strength the 1% lower probability point can be calculated as follow:

$$1\%PV = R - 2.326\ S \qquad \text{------------------} \quad (1)$$

where 1%PV = the 1% lower probability point

R = the extreme fibre stress in bending of the small clear specimens

S = the standard deviation of 'R'

2.326 = the statistical constant corresponding to the 1% probability point on the normal distribution

Pearson (1965) assumed the bending strength of small clear test specimens should be reduced by 9/16 for application to long term loads and in turn by a further 4/5 to allow for accidental overload and other incalculables and again in turn by 93.458/100 to allow for size variation. The overall reduction is thus [(9/16)*(4/5)*(93.458/100)]= 0.4206.

i.e. F = 1%PV * 0.4206

where F = Basic working stress in bending

1%PV = 1% lower probability point of the test specimens.

$$F = 1\%PV \ / \ 2.378 \qquad \text{---------------------(2)}$$

The constant 2.378 is called the reduction factor for bending strength. Combining (1) and (2),

$$F = \frac{R - 2.326\,S}{2.378}$$

Appendix 3

ADJUSTMENT OF TEST DATA TO 12 PERCENT MOISTURE CONTENT [Australian Standard(1979) 2878-1986]

Mack(1979) describes the method used to correct individual test results from seasoned material to 12 percent moisture content. The corrections apply only to standard mechanical test data.

Average corrections per 1% moisture content difference from 12 percent are:

(a) Static bending:

Modulus of rupture	4 %
Modulus of elasticity	1.5%

(b) Compression parallel to the grain:

Maximum crushing strength	5%

When the moisture content at test is greater than 12 percent, the correction is additive; when less subtractive.

APPENDIX 4

Logs and boards Scottsdale material from which small clear specimens were prepared.

	Log no.	Board no.	Length [M]	Mid diameter [mm]	Small end diameter [mm]
1	1	B1A	5.4	530	480
2		B1A2			
3	2	B2A	3.6	720	610
4	3	B3A	3.0	570	570
5	4	B5A	5.4	720	570
6	5	B5A			
7		B5A2			
8		B5A3			
9	6	B10A	3.5	440	420
10	7	D1A2	4.8	460	430
11	8	D2A	3.0	590	580
12	9	D3A	4.8	490	480
13	10	D4A	3.3	540	520
14	11	D6A	4.9	410	350
15	12	G3A	3.3	500	490
16		G3A2			
17	13	G4A	4.8	580	520
18		G4A2			
19	14	G5A	5.4	590	510
20	15	O1A	3.0	230	210
21	16	P1A	4.5	600	530
22	17	P2A	3.6	730	680
23	18	P5A	5.4	540	500
24	19	P8A	3.4	360	360
25		P8A			
26	20	R4A	5.1	470	430
27	21	R5A	3.6	520	500
28	22	R10A	4.5	340	320
29	23	W1A	4.5	500	470
30		W1A2			
31	24	W3A	3.9	640	600
32	25	W4A	3.6	480	430
33	26	W6A	4.5	350	300
34	27	Y3A	3.3	430	400
35	28	Y5A	5.1	490	460
36		Y5A			
37	29	Y8A	4.5	400	380
38	30	Y10A	5.1	440	380
39		Y10A			
40		Y10A2			

APPENDIX 5

EXAMPLE OF A PROFORMA FOR BOARD SAMPLING

AUSTRALIAN NATIONAL UNIVERSITY
DEPARTMENT OF FORESTRY

RESEARCH PROJECT: STRENGTH GROUPING OF 1939 REGROWTH E. REGNANS, VICTORIA
SAMPLE SELECTION PROFORMA

SPECIES		LOG CODE NO.	
ORIGIN		DATE OF MILLING	
AGE		MILLING SITE	
TREE NO.		SELECTORS	
D.B.H.		LOG LENGTH	
		LOG MID DIAMETER	
		LOG SMALL END DIAMETER	
		LOG MID HEIGHT	
		LOG SMALL END HEIGHT	

SAMPLE NO.	L. FROM S.E. END	SECTOR NO.	ANGLE [DEGREE]	RANDOM NO.	SQRT OF RANDOM NO.	S.E. RADIUS [MM]	SAMPLING POINT
1		6	66	0.74	0.860		
2		10	114	0.44	0.663		
3		21	246	0.76	0.872		
4		9	102	0.05	0.224		
5		13	150	0.34	0.583		
6		17	198	0.74	0.860		

APPENDIX 6

MODULUS OF ELASTICITY OF UNSEASONED TIMBER FROM 1939 REGROWTH MOUNTAIN ASH FROM NOOJEE, VICTORIA

File name: 1108MOE.FDT   Date: 1 December 1987
Loading data:
3 PT.
Span = 280
Machine & measuring devices used:
Shim. f.e , Shim. d.g.   (ME(1))   positioned 140 mm from end support
Shim. f.e.   (N)   Shim. d.g.   (mm)   (ME(1))
Sample data is printed in sequence as follows:

Record	Date	Time(hr,min,sec)			* Specimen no.	Depth	Breadth	Max. Force	Max. Fibre Stress	ME(1)
157	871130	10	29	34	* N13	20.6	20.7	558	26.66	13.78
158	871130	10	31	13	* N14	20.6	20.6	545	26.18	10.16
159	871130	10	32	53	* N15	20.6	20.7	553	26.42	10.83
160	871130	10	34	33	* N16	20.6	20.6	563	27.03	10.88
161	871130	10	36	43	* N17	20.5	20.6	563	27.29	9.98
162	871130	10	38	12	* N18	20.6	20.6	548	26.30	14.51
163	871130	10	40	0	* N19	20.6	20.5	553	26.67	9.88
164	871130	10	41	43	* N20	20.7	20.5	560	26.78	10.06
165	871130	10	43	7	* N21	20.4	20.5	553	27.20	12.61
166	871130	10	44	42	* N22	20.5	20.6	550	26.68	13.45
167	871130	10	46	19	* N23	20.5	20.6	550	26.68	12.88
168	871130	10	47	53	* N24	20.5	20.5	563	27.42	12.43

EXAMPLE OF PRINT OUT FOR STATIC BENDING TEST RESULTS

MODULUS OF RUPTURE OF UNSEASONED TIMBER FROM 1939 REGROWTH MOUNTAIN ASH FROM NOOJEE, VICTORIA

File name: 1108MOR5.FDT Date: 1 December 1987
Loading data:
3 PT.
Span = 280
Machine & measuring devices used:
Shim. f.e , Shim. d.e. (ME(1)) positioned 140 mm from end support
Shim. f.e. (N) Shim. d.g. (mm) (ME(1))
Sample data is printed in sequence as follows:

Record	Date	Time(hr,min,sec)			* Specimen no.	Depth	Breadth	Max. Force	Max. Fibre Stress	ME(1)
157	871201	15	51	2	* N13	20.6	20.7	1340	64.07	10.74
158	871201	15	54	8	* N14	20.6	20.6	1328	63.78	9.24
159	871201	15	57	53	* N15	20.6	20.7	1198	57.26	8.61
160	871201	16	0	45	* N16	20.6	20.6	1328	63.78	8.74
161	871201	16	4	11	* N17	20.5	20.6	1098	53.25	6.85
162	871201	16	7	58	* N18	20.6	20.6	1420	68.22	11.88
163	871201	16	11	23	* N19	20.6	20.5	1355	65.42	8.35
164	871201	16	14	49	* N20	20.7	20.5	1203	57.50	7.61
165	871201	16	18	38	* N21	20.4	20.5	1348	66.34	9.77
166	871201	16	21	57	* N22	20.5	20.6	1393	67.56	11.08
167	871201	16	25	5	* N23	20.5	20.6	1320	64.04	11.71
168	871201	16	27	54	* N24	20.5	20.5	1218	59.35	10.21

APPENDIX 7

EXAMPLE OF PRINT OUT FOR COMPRESSION PARALLEL TO THE GRAIN TEST RESULTS

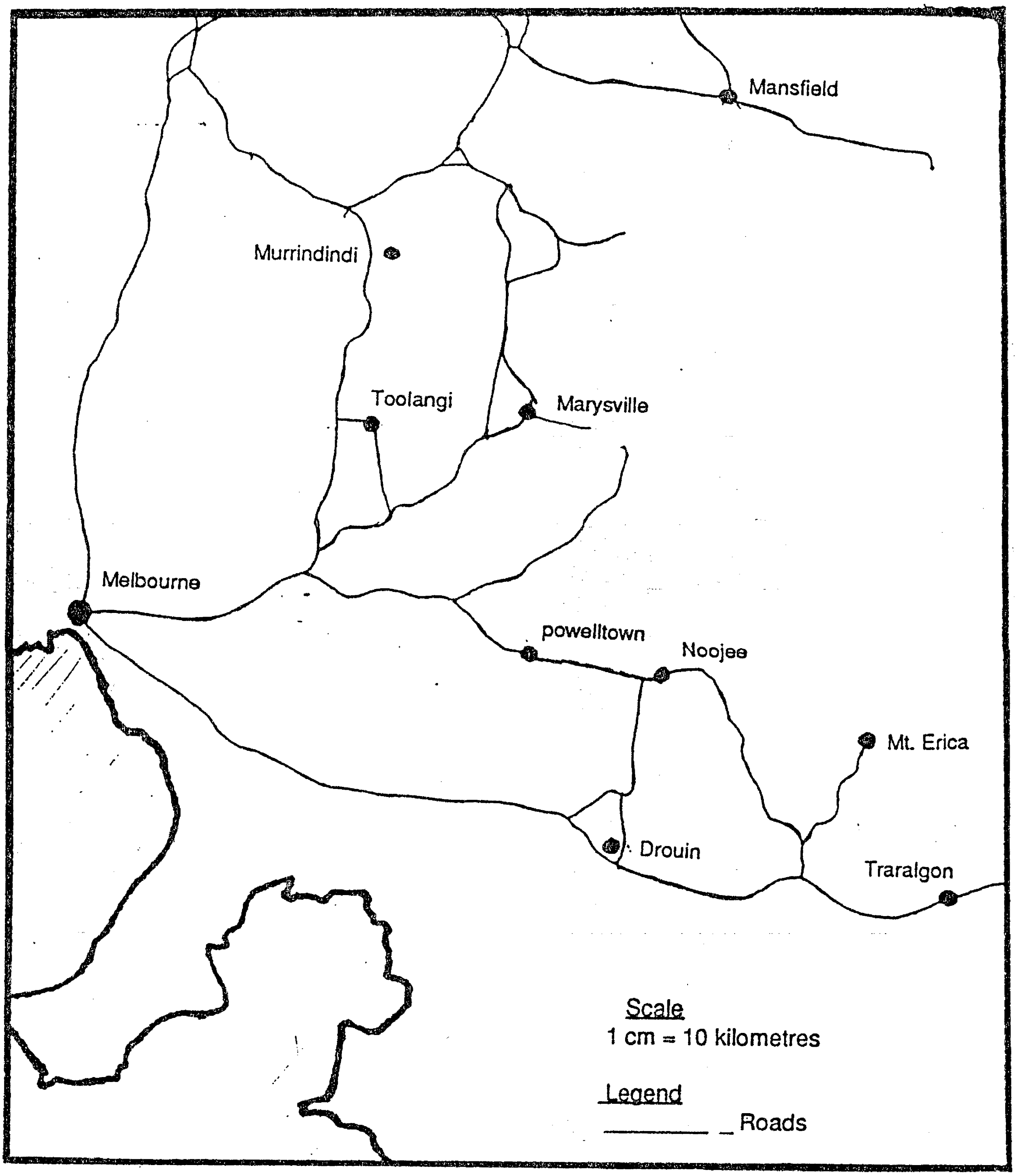
MAXIMUM CRUSHING STRENGTH OF UNSEASONED TIMBER FROM 1939 REGROWTH MOUNTAIN ASH FROM NOOJEE, VICTORIA

File name: 1108COMP.FDT　　Date: 1 December 1987
Loading data:
TENSION/COMP
Gauge Length = 60
Machine & measuring devices used:
Avery f.e , Avery d.e. (ME(1)) positioned 0 mm from end support
Avery f.e. (N) Avery d.g. (mm) (ME(1))
Sample data is printed in sequence as follows:

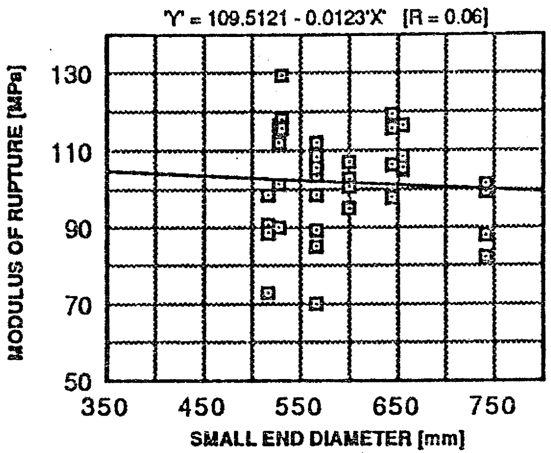
Record	Date	Time(hr,min,sec)			* Specimen no.	Depth	Breadth	Max. Force	MaX. Fibre Stress	ME(1)
157	871126	14	30	35	* N13	20.6	20.7	11572	27.14	3.11
158	871126	14	38	2	* N14	20.7	20.7	12310	28.80	3.07
159	871126	14	43	43	* N15	20.8	20.7	10745	25.02	2.41
160	871126	14	48	20	* N16	20.7	20.7	15350	35.82	3.59
161	871126	14	53	53	* N17	20.6	20.7	12000	28.21	2.40
162	871126	14	58	53	* N18	20.8	20.8	13535	31.36	3.67
163	871126	15	3	53	* N19	20.6	20.6	11852	28.00	2.52
164	871126	15	7	45	* N20	20.6	20.7	11985	28.11	2.90
165	871126	15	11	59	* N21	20.7	20.7	13697	32.04	2.91
166	871126	15	16	3	* N22	20.8	20.8	13992	32.42	3.60
167	871126	15	19	21	* N23	20.7	20.7	11926	27.83	3.00
168	871126	15	24	18	* N24	20.7	20.7	11483	26.80	2.68

APPENDIX 8

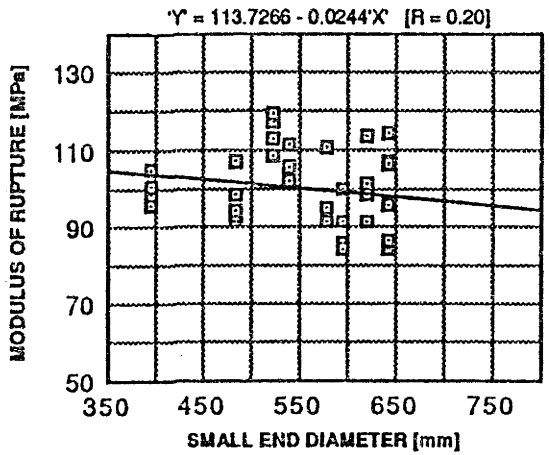
LOCATION OF SAWMILLS SAMPLED



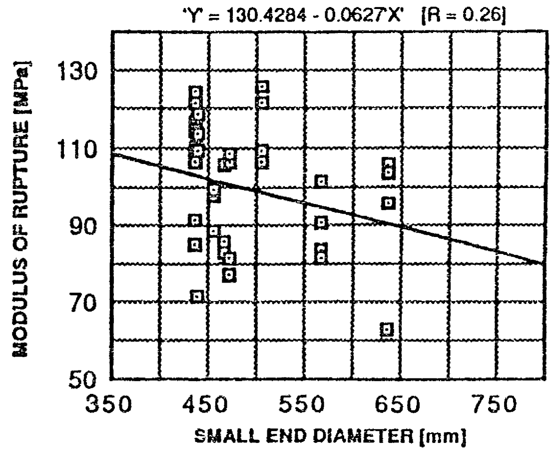
<u>APPENDIX 9.1</u>. Relationships between small end diameter of logs and Modulus of Rupture for seasoned timber of 1939 regrowth mountain ash from 5 localities in Victoria.



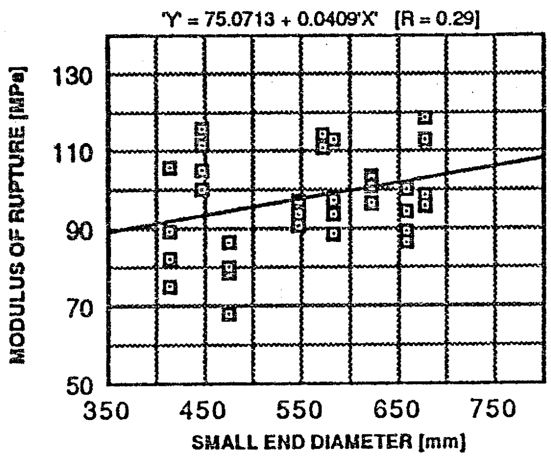
(1) Powelltown



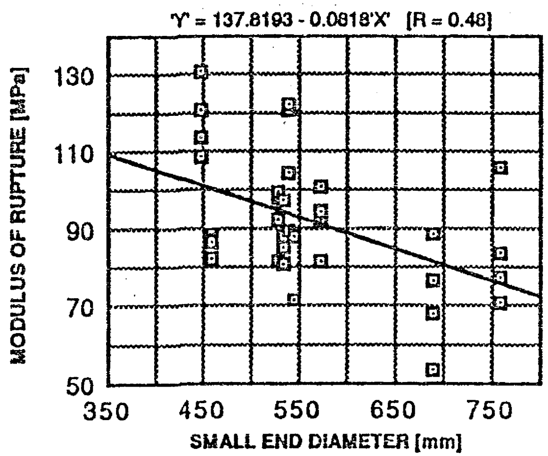
(3) Marysville



(5) Noojee

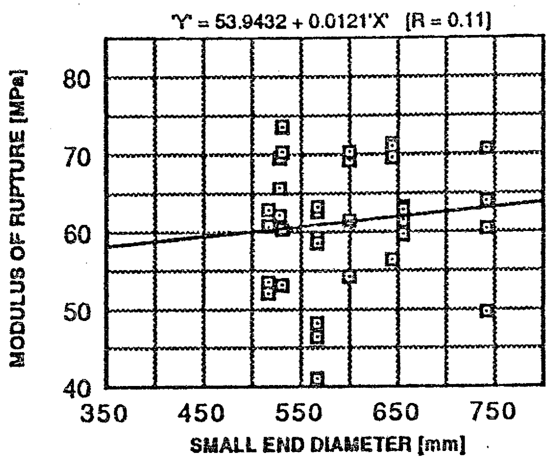


(2) Murrundinid

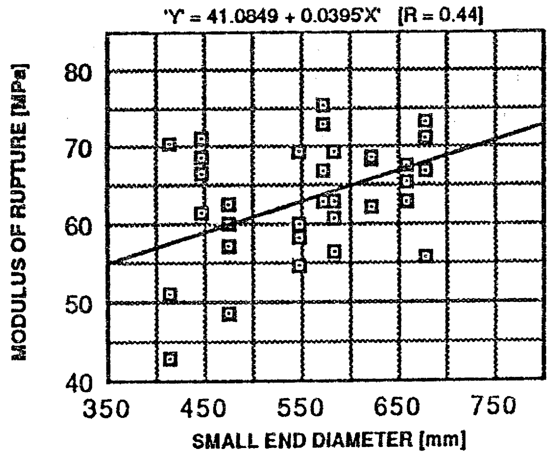


(4) Mt. Erica

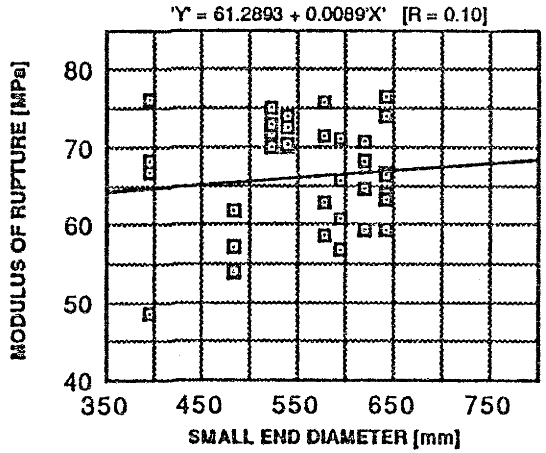
APPENDIX 9.2. Relationships between small end diameter of logs and Modulus of Rupture for unseasoned timber of 1939 regrowth mountain ash from 5 localities in Victoria.



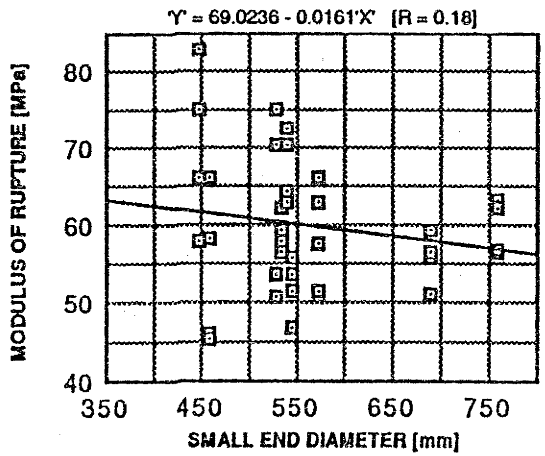
(1) Powelltown



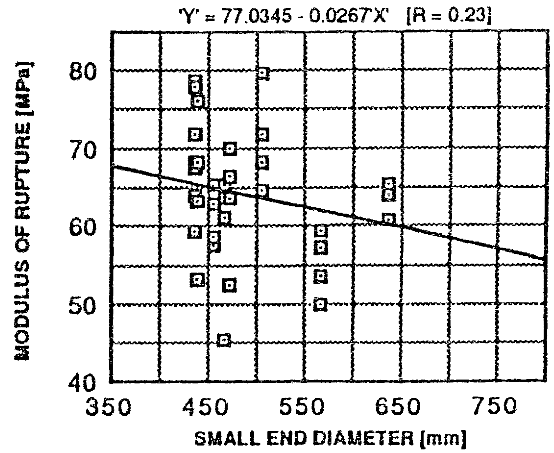
(2) Murrindindi



(3) Marysville



(4) Mt. Erica



(5) Noojee

APPENDIX 10

(From Myint, Nyan(1985) "Generation of the random Series" in " A study on the Autoregressive Model Fitting for the generation of the Irrawaddy stream flow. Unpublished Masters Thesis, Department of Statistics, Institute of Economics, Rangoon, Burma. pp.(191-196).

1. RANDOM NORMAL DEVIATES

The random normal deviates or the normally distributed random variates with mean zero and unit standard deviation can be generated by using the Box-Muller transformation method (Box and Muller, 1958). By this method,

$$X_i = (-2 \ln U_i)1/2 \cos (2\pi U_{i+1})$$

$$X_{i+1} = (-2 \ln U_i)1/2 \sin (2\pi U_{i+1})$$

Where U_1, U_2,...are the uniformly distributed random variates over the interval (0,1), then X_i, i=1,2,.... are independently and normally distributed random variates with mean zero and unit standard deviation.

Neave (1973) suggested the following procedure to obtain more exact tail values. He defined

$$V1 = (2U_i - 1), \quad V2 = (2U_{i+1} - 1)$$

$$S = (V1)2 + (V2)2 \ , \ i = 1,2,....$$

Then, if S > or = 1, discard the two uniform variates U_i, U_{i+1} and use the next two variates in the sequence until S < 1. Then the random normal deviates are generated according to

X_i = V1 (sqrt ((-2 ln S)/S), X_{i+1} = V2 (sqrt ((-2 ln S)/S), i = 1,2,....

Both generators pass the chi-square frequency test, skewness and kurtosis tests for normality and the correlation test and the run test for randomness.

2. COMPUTER PROGRAMME USED TO GENERATE THE RANDOM NORMAL DEVIATES

```
        program ran
        implicit real*8 (a-h,o-x), character*10 (y)
        dimension a(10)
        type *,'Please give the output file name ?'
        read(5,501)y1
        open (unit=2,file=y1,status='new')
        type *,'Howmany Normal Variates do you want to get ?'
        read(5,*)n
        type *,'Give mean and standard deviation ?'
        read(5,*)am,sd
        type *,'Please give the start value between 0 and 1 ?'
        read(5,*)u2
        k=idint(1988*u2)
        do 10 i=1,k
              u2=rand(u2)
10      continue
        do 50 i=1,(n-1)/10+1
           j=1
20         if(j.gt.10) goto 30
              a(j)=0.d0
              a(j+1)=0.d0
              u1=rand(u2)
              u2=rand(u1)
              v1=2.d0*u1-1.d0
              v2=2.d0*u2-1.d0
              s=v1*v1+v2*v2
              if(s.ge.1.d0) goto 20
              x=dsqrt(-2.d0*dlog(s)/s)
              a(j)=v1*x
              a(j+1)=v2*x
```

```
          j=j+2
        goto 20
30      do 40 j=1,10
          a(j)=am+sd*a(j)
40      continue
        write(2,201)(a(j),j=1,10)
50    continue
      type *,'Save Random Number for next run = ',u2
      stop
201   format(10f8.3)
501   format(a10)
      end

      function  rand(x)
      real*8  rand,x
      rand=997.d0*x-idint(997*x)
      return
      end
```

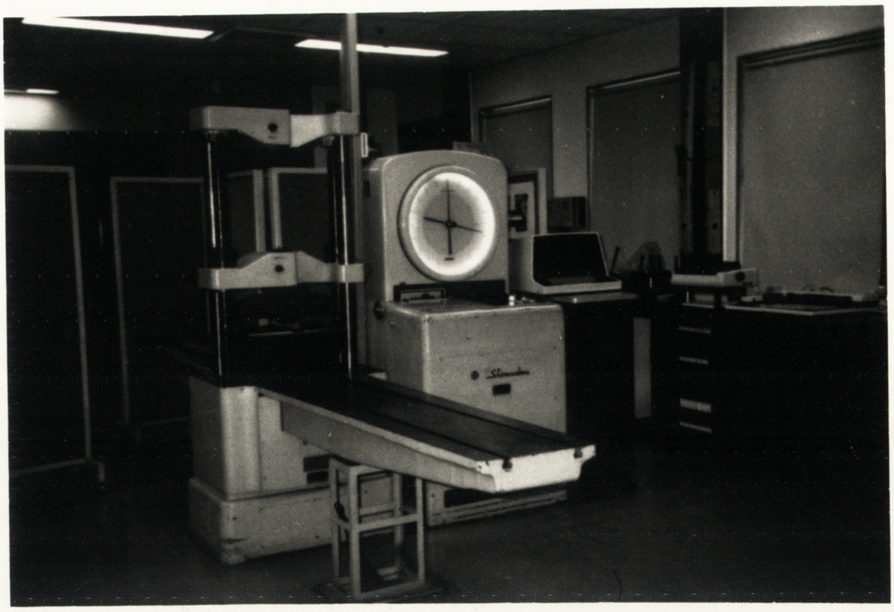


Plate 1. Configurations for Modulus of Rupture test showing the Shimadzu testing machine, the computer, the printer and the plotter.

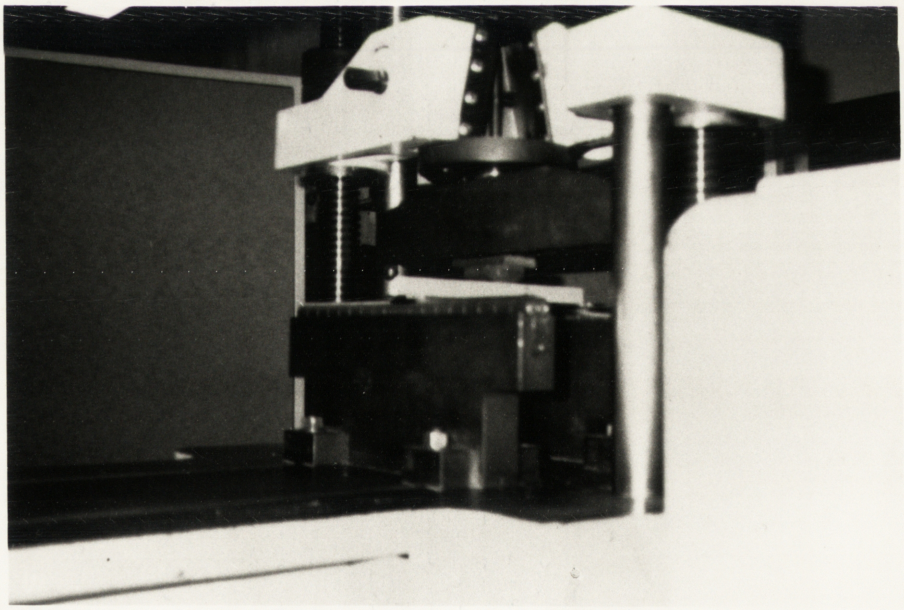


Plate 2. Configurations for Modulus of Rupture test showing the position of the specimen.

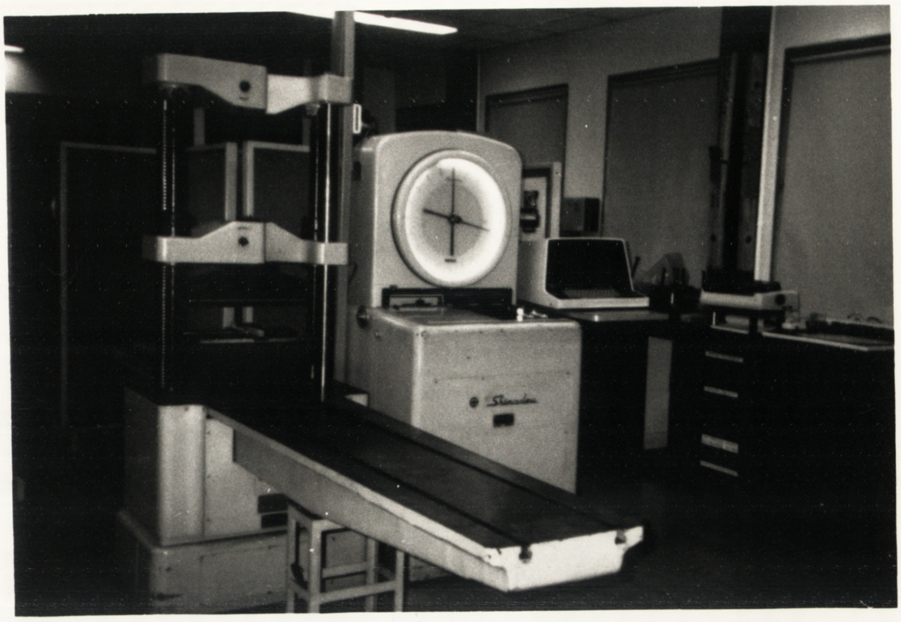


Plate 3. Configurations for Modulus of Elasticity test showing the Shimadzu testing machine, the computer, the printer and the plotter.

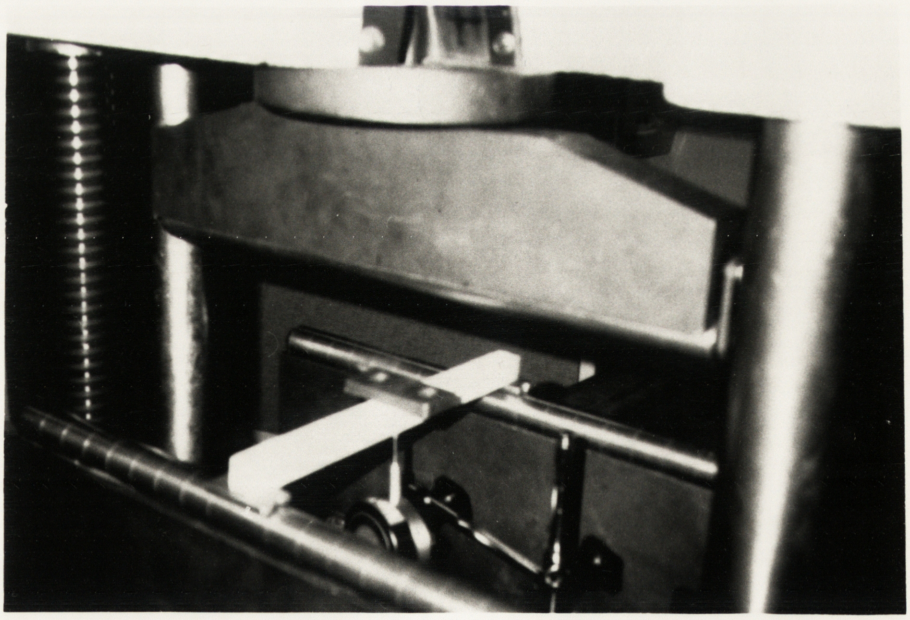


Plate 4. Configurations for Modulus of Elasticity test showing the position of the specimen.

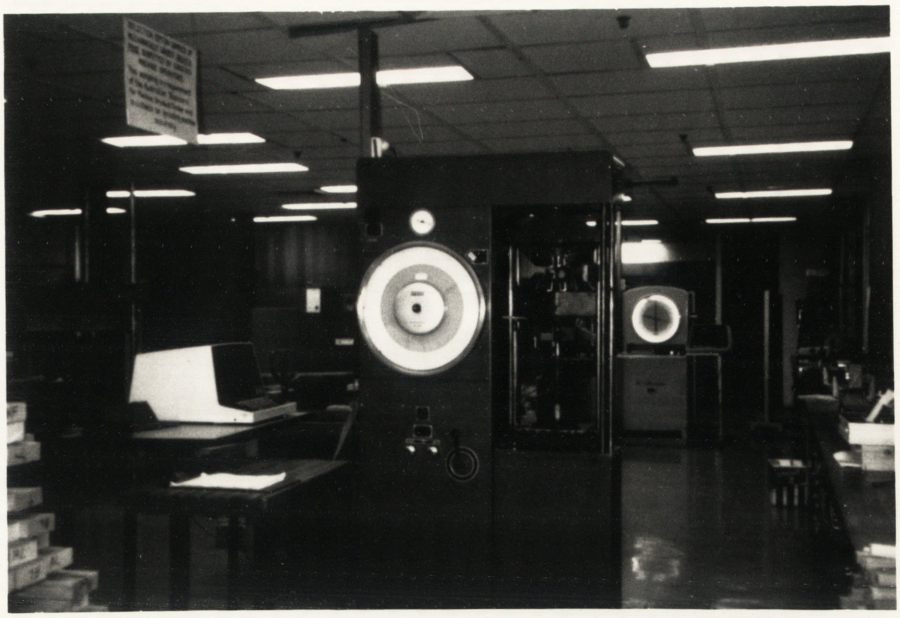


Plate 5. Configurations for Compression parallel to the grain test showing the Avery testing machine, the computer, the printer and the plotter.

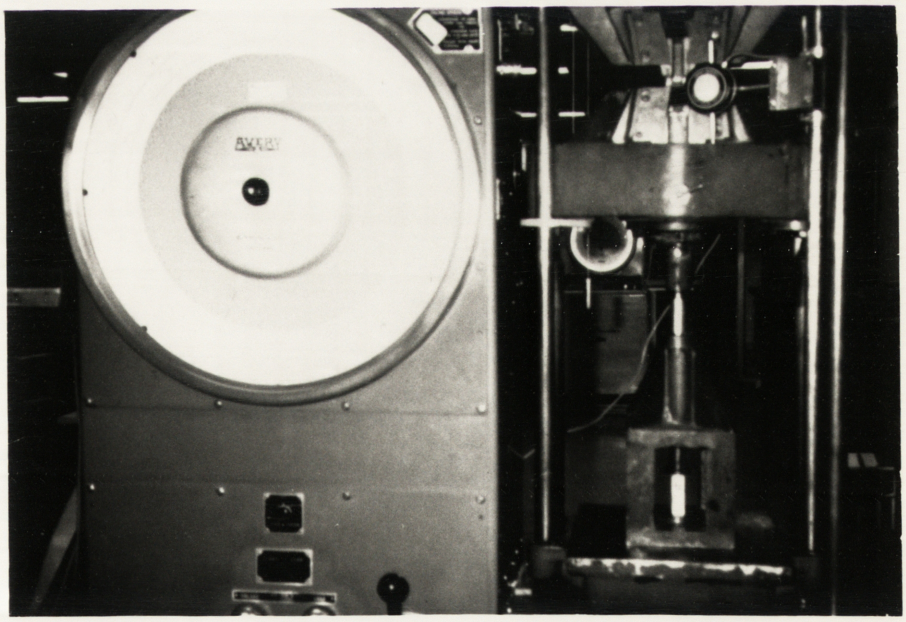


Plate 6. Configurations for Compression parallel to the grain test showing the position of the specimen.

REFERENCES

Anton, A. (1981). Grading Timber for Strength. Topic E8. 20th Forest Products Research Conference, CSIRO, Melbourne, Australia.

-- and Garbellini, A.A. (1981). Mechanical grading of 1926 regrowth mountain ash. Topic E7. 20th Forest Products Research Conference, CSIRO, Melbourne, Australia.

American Institute of Timber Construction (AITC) (1974). Timber construction manual. 2nd ed. John Wiley & Sons. New York. In Meyer & Kellogg (1982).

Ashton, D.H. (1976). The development of Even-aged stands of Eucalyptus regnans F. Muell. in Central Victoria. Aust. J. Bot. 24, 397-424.

Australian Standard (AS 1720 - 1975). SAA Timber Engineering Code. Standard Association of Australia.

Australian Standard (AS 2082 - 1979). Visually Stress - Graded Hardwood for structural purposes. Standard Association of Australia.

Australian Standard (AS 2858 -1986). Timber - Softwood - Visually stress-graded for structural purposes. Standards Association of Australia.

Australian Standard (AS 2878 - 1986). Timber - Classification into strength groups. Standards Association of Australia.

Beckett, R.S (1986). Market opportunities for timber through engineering. Topic 24. 22nd Forest Products Research Conference, CSIRO, Melbourne, Australia.

Bootle, K.R. (1983). Wood in Australia. McGraw Hill Book Company, Sydney.

Bolza, E & Kloot, N.H. (1963). The mechanical properties of 174 Australian timbers. CSIRO Div. For. Prod. Technol. Pap. 25.

Booth, L.G., and Silvester, F.D. (1957). Static bending tests on kerving and red meranti in structural sizes. Timb. Devel. Assoc., England, Test Rec E/TR/14.

Box, G.E.P. and Muller, M.E. (1958). A note on the generation of normal deviates. Ann. Math. Stat., 28, 610-611.

Breitenger, R.P. (1987). Internal report. Division Building Research. CSIRO, Melbourne, Australia.

Chaplin, C.J. and Nevard, E.H. (1935). Strength test of structural timbers. Part I. General principles with data on redwood from Getle and Archangel. For. Prod. Res. Rec. No.2.

Cline, McG., and Heim, A.L.(1912). Tests of structural timbers. U.S. For. Serv. Bull. No.108.

Comben, A.J.(1971). The establishment of provisional stress grades for Nigerian timbers. Nigerian J. For. 1(1), 34-42.

Cooper, K.L. (1953). Preferred stress grades for structural timber. Aust. J. Appli. Sc. Vol. 4. p. 77-83.

Dinwoodie, J.M (1981). Timber: its nature and behaviour. Van Nostrand Reinhold Company, Melbourne, Australia.

Eldgridge, K.G. (1972). Genetic variation in the growth of Eucalyptus regnans from an altitudinal transect of Mount Erica, Victoria. Aust. For. Tim. Bull. No. 46. 46pp.

Epsiloy Jr. E.B. (1978). Strength grouping of Philippine timbers for utilization of less-known species. For. Prod. Res. Ind. Development Board, Tech. Note No. 187, March.

Food and Agricultural Organization [FAO] (1959). Asia-Pacific Regional Grading Rules for teak squares.

Hall, N., Johnston, R.D. and Chippandale, G.M. (1970). Forest trees of Australia. Aust. Gov. Pub. Ser. Canberra, 334 pp.

Hurditch, W.J.(1987). Hardwood sawmilling and its prospects. In "Prospects for Australian hardwood forests". Edited by Dargavel, J. and Sheldon, G. Centre for Resource and Environmental Studies, ANU, Canberra, Australia.

Jane, F.W. (1970). The structure of wood. London, Adam and Charles Block. 2nd ed. 427 pp.

Johnson, R.P.A. (1950). Grading problems that challenge the lumber industry. Proc. For. Prod. Res. Soc. 4, 24-27.

Keating, W. G. (1973). What's in a (Metric) name? For. Prod. Newsletter No. 391. Forest Products Laboratory, CSIRO, South Melbourne, Victoria, Australia.

- (1981). Utilization of mixed species through grouping and standards. Aust. For. 43(4), 233-244.

Kloot, N.H. (1973). The strength group and stress grade systems. Forest Products Newsletter No. 394. CSIRO.

-(1976). Methods of assessing properties. XVI IUFRO World congress. Division V, 76-82.

Kloot, N.H. and Schuster, K.B. (1958a). The effect of cross grain on bending properties of Jarrah scantlings. Aust. J. Appl. Sci. 9: 9-17.

Kloot, H. and Schuster, K.B. (1958b). The effect of gum veins and pockets on the bending properties of jarrah scantlings. CSIRO Asut., Div. For. Prod. Technological Paper No.2.

Lee, I.D.G., Lord, A.D., and Weddel, E.D. (1961). Static bending tests on greenheart in structural sizes. Timb. Devel. Assoc., England, Test Rec. E/TR/20.

Leicester, R.H. (1981). Grouping and selection of species for structural utilization. Div. of Build. Res. Tech. Paper (second series) No. 39. CSIRO, Australia.

Mack, J.J. (1979). Australian methods for mechanically testing small clear specimens of timber. Div. of Build. Res. Tech. Paper (second series) No. 31. CSIRO, Australia.

May, T.K. (1952). Structural lumber, past-present-future. J. For. Prod. Res. Soc. 2, 72-75.

Mendenhall, W. (1983). Introduction to probability and statistics (sixth ed.). Duxbury Press, Boston. 646 pp.

Myint, Nyan.(1985). A study on the autoregressive model fitting for the generation of the Irrawaddy stream flow (unpublished, M.Econ. Thesis). Institute of Economics, Rangoon. 192 pp.

Neave, H.R. (1973). On using the Box-Muller transformation with multiplicative congruential pseudo random number generators. App. Stat. 22, 92-97.

Page, M.W. (1965). Utilization potential of immature logs. CSIRO Forest Products Newsletter. 320:1-2.

Panshin, A.J, De Zeeuw, C. and Brown, H.P.(1964). Textbook of wood technology, Volume I, 2nd. Ed. McGraw Hill Book Company, USA. 643 pp.

Pearson, R.G. (1952)The sampling of timber for standard mechanical tests. Aust. J. Appl. Sci. 3, 25-52.

- (1965). The establishment of working stresses for groups of species. Div. of For. Prod. Tech. Paper No. 35. CSIRO, Australia.

- (1966). Proposed revision of strength grouping system. For. Prod. Newsletter No. 329. Division of Forest Products, CSIRO, South Melbourne, Victoria, Australia. p. 1-4.

Pearson, R.G., Kloot, N.H. & Boyd, J.D. (1962). Timber engineering design handbook. 2nd. Ed. Jacaranda Press , Australia.

Pearson, R.G. and Williams, E.J. (1965). Review of methods for the sampling of timber. For. Prod. J. 8(9), 263-268.

Pong Sono (1974). Merchantable timbers of Thailand. Symposium on Research and Marketing of Southeast-Asian Timbers and Timber products. Organized by the German foundation of International Development (Berlin) and the Government of the Republic of the Philippines, Manila and Los Banos, Philippines. 19-23 Nov. 120-165.

Rodger, A. (1963). A Handbook of the forest products of Burma. Superintendent, Government Printing and Stationery, Rangoon.

Sunley, J. G. (1974). Grade stresses for structural timber. In "The strength properties of timber". The Princes Risborough Laboratory of the Building Research Establishment, England.

Turnbull J.W. and Pryor L.D. (1984). Choice of species and seed sources. In Eucalypts for wood production edited by Hillis W.E and Brown A.G.

U.S. For. Prod. Lab. (1974). Wood Handbook: Wood as an engineering material [USDA Agr. Handb. 72]

Wong, W.C. and Wong, C.N. (1980). Grouping species in plywood manufacture. proc. 11th Commonw. For. Conf., Trinidad. Sept.

Young Eucalypt Program. (1987). Pamphlet. CSIRO. Aust. Div. For. Res. Canberra.